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A framework for preparing cities for the successful implementation of shared autonomous vehicles: An integrative literature review

Marvin Greifenstein [a,*], Alessandro La Delfa [b], Zheng Han [b]

[a] Institute for Mobility (IMO), University of St.Gallen, St.Gallen, Switzerland
[b] Chair of Innovation and Entrepreneurship, Tongji University, Shanghai, China

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ABSTRACT

In response to sustainable mobility paradigms and the transition from private ownership to shared utilization, shared autonomous vehicles (SAVs) may play a pivotal role in future mobility systems. However, SAVs are still emerging, and there is a lack of cohesive frameworks and criteria to evaluate cities' readiness for SAVs. Therefore, this study proposes a new conceptual framework to evaluate city readiness for SAVs, ensuring their integration and bridging an existing research gap. By conducting an integrative literature review, existing research in the field of SAVs is assessed and synthesised in a way that allows new perspectives to emerge. The 34 included publications were inductively coded using Atlas.ti software. As a result, the proposed framework addresses city readiness in five core categories: infrastructure, security & privacy, policy, regulation & legality, innovation, collaboration & economics, and customer/citizen engagement. Infrastructure and policy, regulation & legality were identified as the most crucial of these categories.

1. Introduction

In recent decades, the world has witnessed a transformative shift in the transport sector, driven by global trends, most notably urbanisation, demographic shifts, climate change, and technological innovation (Gao & Zhu, 2022; Trask, 2020). In particular, megacities have emerged as epicentres of economic activity and cultural diversity due to rapid urban expansion and population growth (Buhaug & Urdal, 2013; Javed et al., 2022; Moomaw, 1996; Ottaviano & Peri, 2006). The confluence of these trends, namely higher population density, increased urbanisation, high importance of climate protection and advanced technologies, has created significant challenges specifically for the transport sector (Földes & Csiszar, 2018; Trask, 2020; Ülengin et al., 2018). The most important challenge is a surge in mobility demand, resulting in huge traffic volumes and congestion, rising numbers of accidents and fatalities, lack of physical and digital infrastructure development, and increasing emissions (e.g. fine dust, carbon dioxide, noise) (Hörl et al., 2016; Kopelias et al., 2020; Shaheen & Cohen, 2019).

Many cities have tried to address these challenges by, for example, introducing city toll, increasing parking fees or reducing availability, promoting car sharing or micro-mobility (e.g. Kolleck, 2021; Lian, 2008; Low & Odgers, 2012; Şengül & Mostofi, 2021; Shen et al., 2020). On the one hand, studies have shown positive effects, especially for city tolls or congestion pricing, in terms of significant reductions in congestion and vehicle use (e.g. Cipriani et al., 2019; Litman, 2005; Singichetti et al., 2021). On the other hand, increasing globalisation and demand mean that long-term success is questionable and limited without further action. Meanwhile, autonomous driving technology is emerging as a promising solution to revolutionise the mobility landscape (Alessandrini et al., 2015; Hörl et al., 2016; Narayanan et al., 2020; Silva et al., 2022), with shared autonomous vehicles (SAVs) having the potential to provide a multitude of benefits and alleviate the beforementioned burdens. Once commercially available in reasonable fleet sizes, SAVs also hold the promise of improving road safety, reducing accidents and fatalities and the associated social costs (Fagnant & Kockelman, 2015; Mares et al., 2018; Milakis et al., 2017; Wadud et al., 2016). For example, the WHO suggests that 3 % of a country's GDP is related to the costs of road traffic accidents (WHO, 2023).

Additionally, studies show that SAVs could significantly improve the efficiency of transport and related infrastructure through higher seat utilisation, environmentally friendly, optimised driving and navigation routes, and vehicle platooning (Milakis et al., 2017; NACTO, 2017; Soteropoulos et al., 2019; Wadud et al., 2016). Although such advantages are frequently highlighted in the literature, various studies have

* Corresponding author.
E-mail address: marvin.greifenstein@unisg.ch (M. Greifenstein).

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also reported contrasting findings, underscoring the nuanced and complex nature of SAVs – a true "double-edged sword" with both potential positive and negative real-world impacts that are not yet fully understood. Estimates for different scenarios show a potential for up to 2.8 to 5 million SAV units to be sold annually on a global scale by 2040 (Greifenstein et al., 2024). Thus, it is apparent that it is a pressing issue to find out and that the disadvantages may need to be addressed quickly to avoid negative consequences.

Furthermore, SAV services could also be more inclusive, providing access to mobility for people without driving licence, the disabled and the elderly (Fagnant & Kockelman, 2015). Such services can operate almost 24 h a day (excluding maintenance, repairs, charging, and cleaning), freeing up valuable urban and suburban space and reducing the number of vehicles requiring parking spaces (Fagnant & Kockelman, 2015; INRIX, 2017; Silva et al., 2022; Soteropoulos et al., 2019). However, in addition to these positive impacts, other studies have found that the widespread use of SAVs will increase total vehicle miles travelled (VMT), particularly due to empty runs (Narayanan et al., 2020). Moreover, several studies suggest that low SAV fleet utilization, reduced travel costs lowering mobility barriers, and a resulting increase in travel demand may counteract many of the previously mentioned benefits (Fagnant & Kockelman, 2015; Narayanan et al., 2020; Wang et al., 2020). This may in turn lead to higher VMT, increasing traffic congestion, and greater environmental impacts (emissions), thereby alleviating or fully erasing anticipated improvements in efficiency, sustainability and urban liveability (Fagnant & Kockelman, 2015; Narayanan et al., 2020; Wang et al., 2020). For example, Greenblatt and Shaheen (2015), looking at different assessments of AVs on greenhouse gas (GHG) emissions, found that they could result in anything from an 80 % reduction to a 300 % increase.

Another important advantage is that operators may need fewer staff due to the elimination of drivers. It should be noted that the provision of such a service will still require other labour-intensive activities, such as fleet supervision, possibly a higher number of road patrols or guards, cleaning, maintenance and repairs, etc., which may again offset the benefit of less labour-intensive work, especially in the short to medium term (Fagnant & Kockelman, 2015; Hyland & Mahmassani, 2017; Milakis et al., 2017; Threlfall, 2020).

Finally, one of the most significant impacts is the long-term shift in personal transportation habits. As individuals move away from private car ownership in favour of shared mobility solutions, particularly public transport complemented by SAVs, the overall ecological footprint is expected to decline substantially (Fagnant & Kockelman, 2015; Milakis et al., 2017; Miller & Heard, 2016). However, these environmental benefits are controversial in the literature and should be treated with extreme caution.

An early stage of commercially available SAV services can be witnessed in San Francisco, USA, offered by companies such as Waymo (Fakhrmoosavi et al., 2024), and in Guangzhou, China, by companies such as Pony.ai and WeRide.ai (Dunne & Chen, 2023; Zhao et al., 2023). They mark a significant step towards SAV-enabled mobility in the future, yet the readiness of cities for such a revolution remains uncertain. At the same time, the overall impact of SAVs remains uncertain, as no large-scale commercial SAV service currently exists. To date, there is no real-world evidence to validate or challenge the many academic studies that rely on models and simulations to predict potential SAV scenarios. As a result, the full extent of their benefits remains to be determined.

For this reason, it is important to understand the relevant empirical and conceptual literature, including its thematic focus, as this will enable the discourse on how cities can prepare for the introduction of SAVs and what implementation hurdles can be overcome through adaptation to be reflected upon and advanced (Freemark et al., 2019; Terry & Bachmann, 2019). For example, several studies have already started to examine specific sub-dimensions of SAV deployment, such as parking management and infrastructure adaptations (e.g. Hu et al., 2024; Jin & Ma, 2024; Zhang et al., 2015), health implications (e.g. Sohrabi et al., 2020), or factors influencing public acceptance (e.g. Kalambay et al., 2025). While the literature has also started to holistically explore city readiness for connected autonomous vehicles (CAVs) (e.g. Jiang et al., 2022; Khan et al., 2019) and AVs (e.g. Barnes & Turkel, 2017; Threlfall, 2018, 2020), a key limitation is that, to the best of the authors' knowledge, no existing framework comprehensively addresses city readiness for SAVs. This study seeks to fill this gap by proposing an actionable framework tailored to urban environments.

While the distinction between AVs, CAVs and SAVs may seem minor, the business models (e.g. owned vehicles versus shared vehicles) and customer interfaces (e.g. apps) are completely different (Dean & Kockelman, 2022; Narayanan et al., 2020; Stocker & Shaheen, 2017). Therefore, this review aims to explore the components that affect the implementation of SAVs in our urban mobility systems. In addition, by proposing a new conceptual framework, critical categories and subcategories for SAV integration are delineated, accompanied by targeted actions, thus offering a new perspective in the field. In doing so, this review contributes by filling a practical-knowledge gap as defined by Miles (2017).

The main aim of this paper is to engage with this scarce research area and provide an integrative literature review that identifies the impact of SAVs on urban environments and offers recommendation strategies for cities. In contrast to other types of reviews (e.g. narrative, semi-structured or structured), the integrative literature review aims to assess and synthesize the research on new, emerging topics (Snyder, 2019) – in this review on the emerging topic of SAVs. Further, the integrative literature review allows to creatively produce a new coherent conceptual framework by synthesizing existing literature and ideas which is the primary goal of this review. Specifically, this work seeks to answer the following research question:

How can cities prepare for the adoption of SAVs and what are the categories of actions that will enable the implementation?

The contribution of this review is manifold. For the academic community, it provides a conceptual framework that can serve as a basis for further adaptation, complementation, validation and theory building. For urban planners, city developers, municipal councils, and legislative bodies, this review offers valuable insights into the categories and subcategories that are essential for the successful mass implementation of SAVs. Thus, this review aims to pave the way for the development of more efficient, resilient, and sustainable cities in the age of SAVs.

2. Methodology

2.1. Integrative literature review and process design

In this paper, an integrative literature review is applied, following the procedure described by Torraco (2005) and Snyder (2019). The purpose of an integrative literature review differs from that of a systematic or semi-systematic review, with the main aim to assessing and synthesising literature on a mostly novel and emerging topic (Snyder, 2019). This methodological flexibility allows for the inclusion of diverse perspectives, ensuring that the findings have broad applicability for real-world impact. In doing so, the review accumulates streams of research and creatively generates a new conceptual framework, model, meta-theory, or other unique concept (Torraco, 2004, 2005). As the topic of SAVs is relatively new, an integrative literature review is appropriate and can lead to a preliminary conceptualisation on this new mobility service (as e.g. similar to Nemoto et al., 2021). Furthermore, relatively few peer-reviewed papers are expected to be found, making a systematic or semi-systematic literature review meaningless while increasing the need for an integrative literature review. Nevertheless, the process of conducting an integrative review should be clearly documented. This implies the need for a precise search term, a comprehensive database search and a search strategy with inclusion and exclusion criteria to identify all relevant articles (Torraco, 2005;

Whittemore & Knafl, 2005). This approach may be perceived as lacking rigour compared to structured reviews, meta-analyses, or others. However, if an integrative literature review is thoroughly conducted and documented, the contribution of a new conceptual model or theory can be of high significance (MacInnis, 2011; Snyder, 2019, 2023).

2.2. Search strategy, literature selection and eligibility procedure

The search was conducted in two major databases, namely Web of Science (WoS) and Scopus. The combination of those two databases guarantees a comprehensive scope while mitigating coverage constraints because many publications in the field of transportation research are covered with those two databases (Baas et al., 2020; Birkle et al., 2020). The search was not constrained by any specific time frame and was conducted end of January 2024 and again end of April 2025 to enhance timeliness and relevance. Initially, the inclusion criteria comprised peer-reviewed journal articles and reviews as well as conference paper and reviews. Conversely, all forms of grey literature and non-peer reviewed literature were excluded (e.g. books, book reviews, book chapters, editorial notes, short surveys, notes, editorials, dissertations, magazines, reports, and articles in languages other than English). This procedure is common practice when conducting such literature reviews (cf. Greifenstein, 2024; Prati et al., 2017).

On an operational level, the conducted search used a search term comprising of various keywords related to SAVs and city readiness. As there exist numerous spelling variations, so-called wildcards ("*") were applied where applicable (see Table 1).

2.3. Data collection and analytical approach

The search was executed in two databases and resulted in 256 results as illustrated in Table 2. After removing duplicates, screening the titles, abstracts, and full-texts, just 14 results are suitable to be included in this integrative literature review. Through the title screening many results were removed since publications focused on other fields (−202) and through the abstract screening results were removed because publications focused on other outcomes or had unrelated research endeavours (−21).

However, the author acknowledges the possibility that relevant literature may have been missed due to the exclusion criteria described above. To mitigate this, the reference lists of the eligible studies were systematically screened in a subsequent step, and relevant grey literature was included in the review (Horsley et al., 2011). This additional step enabled the identification of publications not captured in the initial database search, thereby enhancing the robustness of the findings through a broader inclusion of sources. Hereby, the authors have elaborated on the keyword selection process as the initial database search used focused on (related) terms such as "SAV" and "city readiness." During the cross-referencing process, the keyword set was expanded to include broader terms such as "infrastructure, urban policy, safety & security for (S)AVs." This iterative refinement allowed for a more comprehensive and broader identification of relevant sources, particularly during the grey literature screening.

Through the cross-refence check another 20 documents were identified which were mostly from grey literature. The grey literature in this review includes the following types: industry white papers (e.g. reports by McKinsey & Company, KPMG, INRIX), government reports (e.g. UK Royal Automobile Club Foundation, US National Association of City Transportation Officials), book chapters from edited volumes on mobility innovation or magazine articles (e.g. Harvard Business Review). These sources were selected based on their credibility, and contribution to the thematic scope of the review.

Table 2
Search strategy and database search results.

Database	Focus	Search date	Results
Web of Science (WoS)	Multidisciplinary	30/04/25	15
Scopus	Multidisciplinary	30/04/25	241
Total Records Identified			**256**
- Removing duplicates			- 12
- Screening of titles & abstracts			- 223
- Screening of full-text			- 7
Total number of eligible results			**14**
+ Additional records identified through cross-referencing check of eligible studies			+ 20
Total number included in analysis			**34**

The prominence of grey literature in this field reflects the novelty of the topic, which is still emerging within academic discourse. As a result, many foundational insights are currently being shaped by policy institutions, consulting firms, and industry stakeholders. Including such materials allows the review to capture the state-of-the-art in practice and research. With these additions, the total number of publications included in this review increased to 34 (see Table 2).

All articles have been imported to the data analysis software Atlas.ti 23, mainly used for qualitative research, for the coding and data analysis process. Using such qualitative data analysis software for analysis purposes of literature reviews has already been done in the past by e.g. Clements et al. (2022), Karjalainen and Juhola (2021) and Lavissière et al. (2020). In this review, the software Atlas.ti was chosen because it has numerous features for advanced coding, generating co-occurrence tables and further visualisation of the coded data and it is already a proven software using qualitative data on AVs (e.g. Harrow et al., 2018; Soe & Müür, 2020).

The text of the articles was coded by following the process of Strauss and Corbin (1998)), ensuring a nuanced and in-depth analysis. Firstly, open coding was applied to inductively create codes related to SAV adoption in cities. The core textual data of each article, regarding their explanation of actions that need to be executed so that SAVs can be successfully implemented into cities, were identified, and created initial codes. Then, through axial coding the codes were connected to form subcategories through a hierarchy-based topic identification (Creswell & Creswell, 2018; Strauss & Corbin, 1998). Thus, in this axial coding step, connections are drawn from the initial codes derived from the open coding step. Further, this step was guided by cross-validating discussions among the authors to increase validity of the results. Lastly, selective coding, the culminating step, selects and defines core categories that, altogether with the subcategories, connect the codes to form a concept (Creswell & Creswell, 2018; Strauss & Corbin, 1998). Hereby, analytical abstraction has led the higher-order subcategories to aggregated categories which overall resulted in a conceptual framework.

3. Findings

This chapter highlights the main findings of this integrative literature review by providing a conceptual framework for how cities can prepare for SAVs, derived from all the codes, subcategories, and categories. The analysis resulted in 25 codes, which were grouped into eleven subcategories and five categories, namely *infrastructure, policy, regulation & legality, innovation, collaboration & economics, security & privacy,* and

Table 1
Keywords and search term employed for the integrative literature search.

"shared autonomous vehicle*" OR "SAV" OR "SAVs" OR "autonomous vehicle*" OR "AV" OR "AVs" OR "CAV" OR "CAVs"
AND
"city readiness" OR "urban readiness" OR "city impact" OR "urban impact" OR "city preparation" OR "urban preparation"

customer/ citizen (see Fig. 1). The structure of the conceptual framework partly follows the socio-technical transition theory of Geels (2002) and conceptualises the landscape developments and socio-technical regimes identified in the literature. Table 3 provides insight into the prevalence of each subcategory in the literature.

3.1. Infrastructure

Efficient operation and full exploitation of SAVs' capabilities require specific developments in both physical and digital infrastructures. The *physical infrastructure*, such as roadway conditions, structures, smart infrastructure, high-tech roadside facilities, and maintenance/ repair, needs to be updated or adapted to successfully implement SAVs in cities. Meanwhile, the *digital infrastructure*, such as cyber network availability, cyber data analytics or sharing platforms & management, must be improved to support the demand for data transmission between SAVs, infrastructure, and/ or their control centres. Overall, proactively upgrading infrastructure is pivotal for the seamless integration of SAVs into urban transportation ecosystems. This category *infrastructure* generated 337 quotes during the coding process, making it the category with the most codes compared to all other categories. The number of quotes is the result of the coding process of counting quotes from publications that extensively deal with or cover a particular code, subcategory, and category. Physical infrastructure was investigated in 27 out of 34 articles (79 %) and digital infrastructure in 26 articles (76 %), making it also the most investigated subcategory (see Table 3).

3.1.1. Physical infrastructure

Research shows that the introduction of SAVs requires specific updates or partial/ full adaptations of existing *physical infrastructure*. The physical infrastructure subcategory can be subdivided into roadway conditions, structures, smart infrastructure, high-tech roadside facilities, and maintenance and repair of the physical infrastructure. Roadway conditions include, for example, the road surface, road condition, road

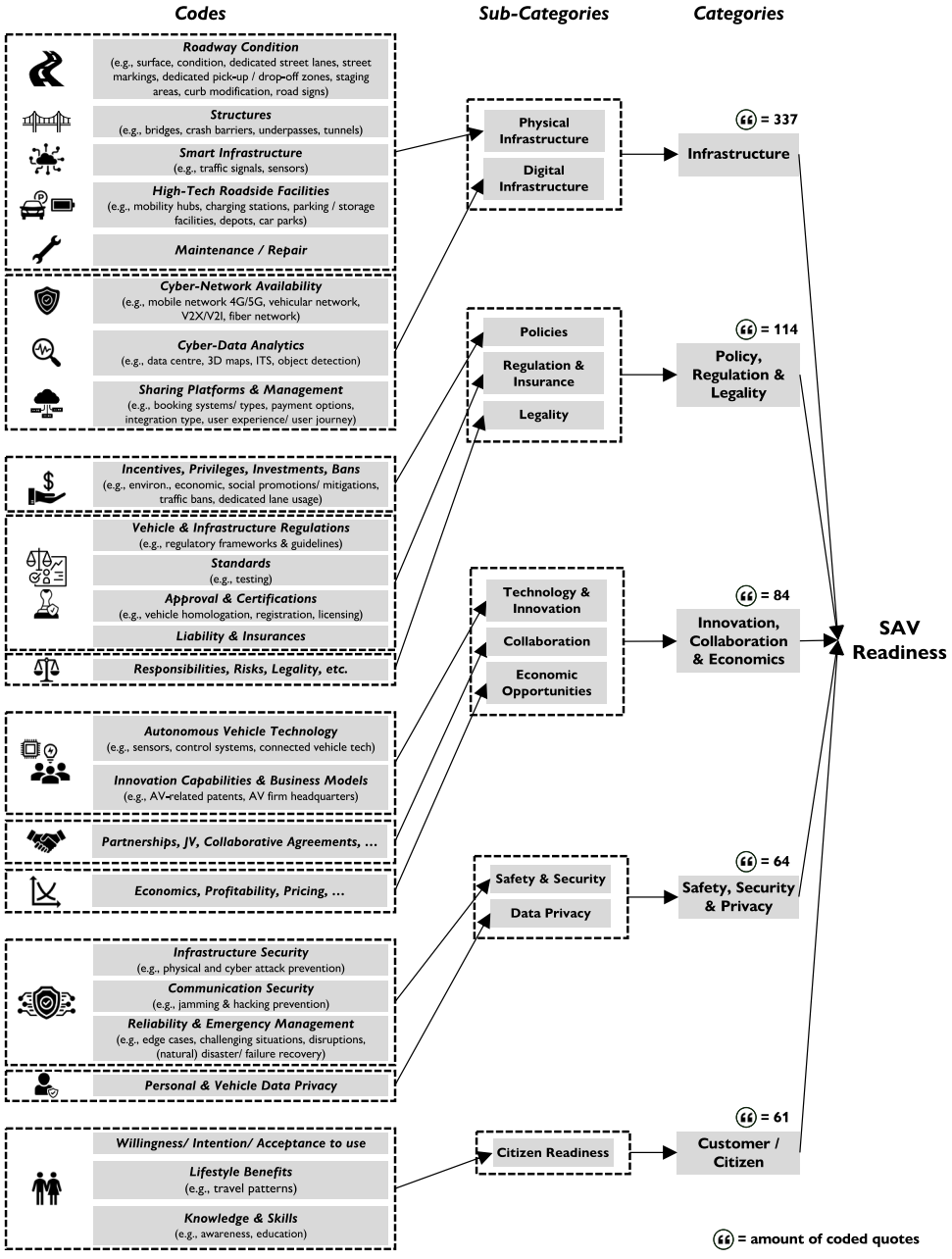


Fig. 1. Conceptual framework with categories, subcategories and codes to enable the deployment of SAVs in cities.

Table 3
The frequency of items mentioned by the included articles in each subcategory.

Included Articles	Categories & Subcategories										
	Infrastructure		Security & Privacy		Policy, Regulation, Legality			Economic Opportunities			Citizen Readiness
	Physical	Digital	Security & Safety	Data Privacy	Policies	Regulation & Insurance	Legality	Technology & Innovation	Collab-oration	Economics, Pricing, Profitability	
Kovačić et al. (2022)	•	•	•	•				•		•	•
Alipour and Dia (2023)					•						•
Jiang et al. (2022)	•	•	•	•	•	•		•			•
Khan et al. (2019)	•	•	•		•	•					•
Heinrichs et al. (2019)	•										
Acheampong et al. (2023)			•		•			•			•
van Arem et al. (2019)								•	•		
Zomarev and Rozhenko (2020)	•	•			•	•					
Stephanedes et al. (2019)	•	•	•	•		•	•	•			•
Alawadhi et al. (2020b)					•	•		•			•
Barnes and Turkel (2017)	•	•									
Duvall et al. (2019)	•	•			•			•	•	•	
Fagnant and Kockelman (2015)	•	•	•	•	•	•		•		•	
INRIX (2017)	•	•									•
Johnson (2017)	•	•	•	•	•	•				•	•
Kimley-Horn (2016)	•	•	•	•	•		•		•	•	•
Threlfall (2020)	•	•	•	•	•	•	•	•	•		•
Mares et al. (2018)	•				•			•		•	
NACTO (2017)	•	•	•		•			•	•	•	•
Oliver et al. (2018)	•	•			•					•	
Saeed (2019)	•	•	•		•	•		•			•
Sheehan et al. (2019)			•								
Soteropoulos et al. (2019)	•										
Sparrow and Howard (2020)	•	•		•	•			•			
Taiebat et al. (2018)	•	•			•	•		•		•	•
Terry and Bachmann (2019)	•	•			•			•		•	
Wadud et al. (2016)		•			•	•		•			
Dokic et al. (2015)		•	•	•		•	•	•			•
Milakis et al. (2017)	•	•	•		•			•		•	•
Total No.	**22**	**21**	**14**	**9**	**20**	**12**	**4**	**18**	**5**	**11**	**16**
(%)	**76**	**72**	**48**	**31**	**69**	**41**	**14**	**62**	**17**	**38**	**55**

markings, but also dedicated street lanes or pick-up/ drop-off zones/ staging areas that need to be in place for the successful operation of SAV services (Duvall et al., 2019; Heinrichs et al., 2019; Johnson, 2017; Khan et al., 2019; Oliver et al., 2018; Porter et al., 2018; Sparrow & Howard, 2020; Terry & Bachmann, 2019). In addition, curb modifications or clear road signage/ signs could also influence a city's readiness for SAVs. Saeed (2019) found that design modifications, such as reconfiguring lane widths, are useful when AVs are on the road. He also suggests that lane markings should be improved, and compatible, easily identifiable signs should be displayed. Johnson (2017) focuses on the readiness of the road network for CAVs in the UK but collects that the characteristics directly related to the road (e.g. surface, road markings, road layout, speed bumps), as well as structures such as bridges, tunnels, crash barriers, or underpasses, could have an impact on the successful deployment of AVs in cities. As such, structures also have an impact on the readiness of SAVs, as they could potentially pose adoption challenges for SAV vendors. Next, smart infrastructure has been mentioned by several sources as helpful for SAVs to navigate in city streets (e.g. Oliver et al., 2018; Saeed, 2019; Taiebat et al., 2018). Smart infrastructure encompasses road or street signage sensors, intelligent traffic lights, advanced traffic management systems, smart parking meters or even curb modifications with sensors, aimed to enhance V2I communication (e.g. Duvall et al., 2019; Johnson, 2017; Terry & Bachmann, 2019; Lukovics and Ujházi, 2024). For example, Duvall et al. (2019) suggest that curbs could generate revenue if they are dynamically priced and smart parking meters or curb sensors are installed. Additionally, so called high-tech curb side or road side facilities such as mobility hubs, charging stations, parking or storage facilities, depots and car parks might become essential when most road trips are made by SAVs (Kovačić et al., 2022; Saeed, 2019; Soteropoulos et al., 2019). NACTO illustrates AV-enabled cities with flexible mobility hubs or zones, where trips can be coordinated, and passengers can be easily picked up and dropped off. Furthermore, demand-based charging stations or occupancy-based congestion pricing, as well as retrofittable parking garages, prepare cities for SAVs. Eventually, it is highly important that the physical infrastructure is well maintained and repaired when necessary to minimise the risk of misbehaviour by SAVs. All the previously mentioned infrastructural characteristics such as roadway condition, structures or high-tech roadside facilities should be regularly maintained for SAVs to operate effectively (Jiang et al., 2022; Milakis et al., 2017). This may also entail that these maintenance and repair procedures need to be done more regularly than today (Duvall et al., 2019).

3.1.2. Digital infrastructure

The subcategory of *digital infrastructure* can be broken down into cyber network availability, cyber data analytics, and sharing platforms & management, which play an essential role in a city's readiness for SAVs. A critical aspect of the digital infrastructure is cyber network availability. This includes the availability of mobile data networks (e.g. 4G/5 G), vehicular networks (e.g. vehicle-to-vehicle, V2V, and vehicle-to-infrastructure, V2I, communication technologies), and fibre networks (e.g. citywide connectivity) (Khan et al., 2019; Terry & Bachmann, 2019; Threlfall, 2020). The impact of a reliable high-speed internet connectivity has been found to be of paramount importance for CAVs (Khan et al., 2019), and therefore also for SAVs. Thus, a citywide coverage of a good mobile network contributes to and increases the adoption possibilities of SAVs. Furthermore, Terry and Bachmann (2019) predict that vehicles will need to communicate with each other, mitigating the need for additional infrastructure and requiring V2I connectivity for full autonomy. Another element of the digital infrastructure that will prepare cities for the commercial deployment of SAVs is cyber data analytics (INRIX, 2017; Khan et al., 2019; Oliver et al., 2018; Stephanedes et al., 2019). This code includes, for example, the availability of data centres to efficiently process and analyse the large amounts of data generated by SAVs, a critical component for an efficient and safe operations (Khan et al., 2019). In addition, 3D maps of operational design domains (ODDs) or even entire cities are pivotal for the efficient, safe and reliable operation of SAVs (INRIX, 2017). Intelligent transportation systems (ITS), including sensor-equipped infrastructure and object detection technology, among others, support SAVs in their operations (Khan et al., 2019). Overall, the constantly generated and consumed data from SAVs needs to be processed and analysed, making cyber data analytics an important component of a city's digital infrastructure readiness. Finally, sharing platforms & management includes the entire user experience and journey of booking and paying for SAV trips, but also, e.g., the back-end management of SAV fleets, pooling algorithms, and more (Kimley-Horn, 2016; Milakis et al., 2017; NACTO, 2017; Taiebat et al., 2018). This is an important code that has not previously been explored in urban readiness studies, which have mostly focused on AVs or CAVs (e.g. Jiang et al., 2022; Khan et al., 2019; Threlfall, 2020). Additionally, NACTO (2017) states that demand should be matched and that within cities, the most vibrant areas with high demand should be served, which may not be the densest areas as they often already have a high supply of high-capacity transit. Sparrow and Howard (2020) highlight that mobility providers will need to guarantee their customers a certain level of service from the SAV trip, including high reliability. Ultimately, SAV fleets can be continuously rerouted in cities to meet real-time demand, while also providing either non-pooled or pooled rides, and vendors will need to be pe prepared to have all the associated infrastructure (e.g. apps, algorithms, fleet management) in place (Golbabaei et al., 2020; Hyland & Mahmassani, 2017).

The challenge of retrofitting/ adapting existing infrastructure or building up new infrastructure elements with niche or novel innovations, which is costly and time consuming, reflects the inertia of established transport infrastructure regimes. To overcome lock-in effects and the inertia of changing transport infrastructure, cities have created pilot projects or test areas that serve as semi-protected niche environments for experimentation with SAV-specific infrastructure. The niche innovations allow cities to learn and refine technologies in a controlled setting, demonstrating that infrastructure changes for SAVs can be tested at the micro level before being implemented at the *meso* or macro level and evolving into sociotechnical landscapes (Geels, 2002).

3.2. Policy, regulation & legality

To effectively regulate the use of SAVs, policies and regulations must be adjusted to address not only traditional issues such as licensing, liability, and road use rules for car users, cyclists, and pedestrians, but also extensively updated to address unique challenges posed by autonomous navigation, data security, and vehicle-to-infrastructure communication. By considering these factors, policymakers can ensure that regulations promote safe and equitable SAV-enabled mobility while also addressing broader societal challenges. Without stringent regulations, private SAV service providers may operate their fleets in a manner that is driven purely by profitability without any constraints and may not be socially beneficial, e.g. leading to increased traffic congestion, compromised user privacy, and widened social inequities. The *policy, regulation & legality* category generated 114 quotes during the coding process, making it the category with the second most codes compared to all other categories. Policy was examined in 23 out of 34 articles (68 %), making it the third most investigated subcategory. Regulation & insurance was examined in 14 articles (41 %) and legality in just 5 articles (15 %) (see Table 3). Thus, policies are seen as a very important sub-category that enables cities to prepare for the successful deployment of SAVs, while legality is not seen as a pressing issue.

3.2.1. Policies

By implementing policies that incentivize vehicle sharing and ride-sharing services, governments can significantly reduce carbon emissions and urban congestion, making the use of SAVs a cornerstone of sustainable urban transportation (Jiang et al., 2022). The commitment of national, state, and/ or local administrations to promote reforms and

policies that enable the deployment and use of SAVs reflects a city's level of readiness (Johnson, 2017; Khan et al., 2019). For example, legalising the use of dedicated lanes for SAVs or banning public traffic on certain streets may be efforts of innovative transportation departments of cities that see high potential in SAVs (Fagnant & Kockelman, 2015; Khan et al., 2019). Thus, investments by cities specifically dedicated to testing and deploying SAV regulations or infrastructure could also be an indication of higher readiness for SAVs (Khan et al., 2019; Saeed, 2019). However, while SAVs are said to bring many advantages, it is important that all individuals benefit from such services and not only those with a good household income and access to infrastructure (Alipour & Dia, 2023). To some extent, policies should ensure that SAV services are affordable, inclusive, and accessible to all (Alipour & Dia, 2023; Jiang et al., 2022). By applying either incentives and privileges or prohibitions and bans, each country, state, and local authority can actively influence and control the commercialisation of SAV services, as well as their social, environmental, and economic impacts.

3.2.2. *Regulation & insurance*

States and cities need to revise their regulatory frameworks to include specific licensing requirements, safety and performance standards, approvals, and testing protocols for SAVs. This update should also address liability and insurance challenges, such as accident liability and privacy concerns. All these components are part of this regulation & insurance subcategory. First, vehicle and infrastructure regulations will need to be updated. Possible regulations can range from the total number of SAVs being allowed on the road to regulations on where they can pick up and drop off customers or where they can be parked (Fagnant & Kockelman, 2015). Next, standards that are internationally agreed upon and harmonized are a prerequisite for AVs, including, for example, standardization for testing, vehicle certification, traffic signals, V2V, and V2I (Dokic et al., 2015). Ensuring public safety and building trust in SAV technology requires systematic vehicle registration, licensing, certification, and approval processes, including international homologation standards (Dokic et al., 2015; Fagnant & Kockelman, 2015; Jiang et al., 2022; Khan et al., 2019). Moreover, these processes are important to enable scalability and thus the emergence of entire SAV fleets rather than individual approvals for just a few vehicles. Lastly, proactively addressing these new liability and insurance challenges is crucial before the widespread commercial availability of SAVs to ensure a smooth transition and safeguard all road users. Vendors will need to prove that the technology is safe and that operations will work properly in specific ODDs or even beyond in entire cities. Fagnant and Kockelman (2015) point out that no matter how safe AVs will become, there will always be unforeseen and unplanned situations that result in crashes or unpleasant outcomes. Even until today, there are unresolved liability issues that countries, states, and cities will need to prepare for once SAVs are on the road. In addition, insurance companies will need to prepare policies and contracts for SAVs. This includes determining who will be liable for crashes and collisions and how insurers can prepare insurance policies for them, as well as other liability issues, such as whether passengers should remain in the vehicle, how to mark a broken down vehicle, and more (Alawadhi et al., 2020a; Fagnant & Kockelman, 2015; Wadud et al., 2016).

3.2.3. *Legality*

The legal framework for AVs is significantly influenced by the Vienna Convention of 1968, which, due to its original design for human drivers, has presented substantial barriers to AV integration (Dokic et al., 2015). Amendments such as the adaptation of Article 1 and the introduction of Article 34 BIS, aim to mitigate these obstacles by recognizing the legitimacy of autonomous driving technologies (United Nations, 2020). Nevertheless, it has been noted in the literature that there is a lack of appropriate legal frameworks and differences between countries that hinder the deployment of AVs or have a more relaxed view on it, allowing for faster deployments (Dokic et al., 2015; Kimley-Horn, 2016; Threlfall, 2020). As SAVs advance and become more integrated into urban environments, it is anticipated that legal frameworks will undergo continuous adaptation and expansion. This evolution is key to ensure that laws remain relevant and effective in governing the deployment and operation of SAVs.

Thus, another critical category is *policy, regulation & legality* as there is a consensus across the literature that existing traffic laws, vehicle regulations, standards and policies are not sufficient for the scalable deployment of SAVs, and that cities and countries need to create new policies for SAV vehicle testing, liability, safety standards and more. As a result, niche policy experiments in the form of individual vehicle approvals, special regulations for test vehicles, or temporary exemptions that allow SAV trials are currently emerging and can be seen in many countries and environments (micro level, novel configurations), but simultaneously limit their scope. In the coming years, it will be crucial to move from these small-scale policy and regulatory experiments to the *meso* level to enable a patchwork of regimes (Geels, 2002) that would allow scalable deployment, large-scale vehicle homologation processes, regulations and more.

3.3. *Innovation, collaboration & economics*

SAVs have the potential to drive innovation and new technological developments, catalyse the emergence of new business models, foster collaborative opportunities, and enhance autonomous driving solutions. Further, SAVs enable new business models such as shared mobility services that can increase efficiency and reduce transportation costs. The category of *innovation, collaboration & economics* generated 84 quotes during the coding process. The subcategories technology & innovation were mentioned in 23 out of 34 articles (62 %), making it together with *policies* the third most investigated subcategory. Collaboration was mentioned in only 6 articles (18 %), and economic opportunities in 14 articles (41 %) (see Table 3).

3.3.1. *Technology & innovation*

The *technology & innovation* subcategory includes autonomous vehicle technology such as sensors, control systems, connected vehicle technology and innovation capabilities of cities. It also highlights how a city's commitment to innovation, through investments in tech hubs and supportive policies, amplifies these technological advancements. Any SAV that will be homologated and approved to drive on public roads must not only meet comprehensive standards related to safety, functionality, efficiency, and reliability to ensure operational excellence but also achieve high levels of comfort and reliability, providing robust and comfortable driving experiences (Acheampong et al., 2023; Dokic et al., 2015; Duvall et al., 2019; Threlfall, 2020). Thus, an interplay of various factors in regard to the AV technology and the AV software itself must be mature enough to meet all requirements and comply to the regulations and standards (Acheampong et al., 2023). The corresponding validation process is highly complex and requires combined vehicle architectures containing a large amount of data, e.g. from sensors and communication devices, and algorithms (Dokic et al., 2015). In addition, the vehicles need to read, analyse, and interpret complex situations while communicating with other vehicles and/or the infrastructure (e.g. sensors, control centre) (Terry & Bachmann, 2019). Hence, the AV technology and component maturity as well as the communication and connected services, with e.g. the infrastructure, plays an important role on the SAV readiness of a city. Furthermore, rather practical measures to the subcategory of technology & innovation relating mostly to innovation capabilities and business models are affiliated by Threlfall (2020). He includes, for example, measures such as a cities' or countries' industry investment in AV, AV related patents, headquarters of AV related firms and the innovation capability of each country to identify the readiness of cities for the introduction of AVs. Duvall et al. (2019) expand the business model considerations by suggesting that vendors could focus on collecting user fees for utilization of SAV-enhanced infrastructure (e.g.

dedicated lane usage) or operate entire SAVs fleets on behalf of cities.

3.3.2. Collaboration

SAVs are part of a fundamental shift in urban transportation, necessitating collaboration across diverse stakeholders including government agencies, technology developers, urban planners, and public transport authorities to facilitate this transition (van Arem et al., 2019). Partnerships and joint ventures, such as formal agreements or memoranda of understanding, allow vendors to focus on their core competencies while ensuring cost effectiveness and coordination of the SAV ecosystem (Duvall et al., 2019; Kimley-Horn, 2016; van Arem et al., 2019). NACTO (2017) recommends regional collaboration to improve interoperability and integration, thereby simplifying the use of SAV services for customers in specific cities or regions. Threlfall (2020) argues that the rapid development and disruptiveness of AV technology, and therefore of SAVs, makes collaboration among various stakeholders essential.

3.3.3. Economic opportunities

Economics is central in shaping the development, deployment, and adoption of every innovation, including new products and services such as SAVs (Oliver et al., 2018). It will decide on where and how SAVs begin to operate and additionally on the pricing and profitability for vendors (Duvall et al., 2019; Fagnant & Kockelman, 2015; Johnson, 2017; Mares et al., 2018). Given the high initial cost associated with SAV services, they are most likely to be deployed in dense urban areas where high demand for trips makes operation and maintenance more cost-efficient (Fagnant & Kockelman, 2015; Oliver et al., 2018). However, it is not just the vehicles and self-driving software and hardware themselves that are very cost-intensive (e.g. 15 % higher than non-autonomous vehicles when widely deployed), but also the infrastructure and development of operations and related services (Johnson, 2017; Mares et al., 2018). Duvall et al. (2019) suggest bundling smaller capital investments across different regions to achieve economies of scale, a strategy that is particularly relevant and effective for financing the capital-intensive infrastructure changes required for SAVs. Municipal governments may, for example, apply for infrastructure grants, issue green or mobility bonds, or allocate portions of the required investments through co-financing opportunities such as congestion/ infrastructure pricing revenues. Hereby, funding mechanisms and budgeting strategies for infrastructure and services related to SAV deployment may also need to come to some extent from federal, state and municipal governments or authorities, alongside private investment, further exacerbating the current funding gap (Duvall et al., 2019; Mares et al., 2018). Cities with limited budget might consider rolling out SAVs geographically or functionally (e.g. starting with specific neighbourhoods or routes) to distribute upfront costs. Public-private partnerships are another mechanism enabling cities to split parts of the investment risks while ensuring (performance based) service and infrastructure delivery. Hereby, development-based taxation reductions or SAV-related service charges for pick-up/drop-off stops, curbside parking or empty runs could offer efficient income streams. Thus, public authorities and operators can identify several new revenue streams, such as for example the listed public-private partnerships, to mitigate the funding gap (Duvall et al., 2019). In addition, pricing determine if the network is reliable not only for users but also for vendors as a reasonable pricing makes the trips and links accessible to users while supporting viability of transit and commuting options (Johnson, 2017).

The challenges circling around the category of *innovation, collaboration & economic opportunities* are mainly related to multi-stakeholder partnerships, innovation and commercialisation of AV technology, novel business models, and funding mechanism. Using Geels (2002) socio-technical framework, it can be interpreted that existing mobility structures and established institutions/ companies such as municipal transport departments and transit operators may inadvertently resist change in order to protect their established domain or for political reasons, for example. However, bringing SAVs to the macro/ scalable landscape level will require deliberate collaboration, especially public-private partnerships, bringing together new entrants (e.g., technology firms, innovative mobility start-ups) as niche actors with established players and public authorities. This finding aligns with the notion that regime change, bringing a product/service from the niche (micro level) to the scalable public (macro level/ landscape), often requires the support of incumbent and new actors (Geels, 2002).

3.4. Safety, security & privacy

Given that SAVs collect and store sensitive data, including personal user information and real-time operational data, securing this information against unauthorized access is critical to maintaining user privacy and operational integrity. This involves protecting them from physical and cyber-attacks. Measures and protocols can be taken to prevent devices from being hacked and to ensure continuous digital access even during and after such disasters/failures. By implementing multifaceted and robust security measures such as end-to-end encryption, regular security audits, and real-time threat monitoring, risks to SAV operations can be significantly minimized, ensuring their efficient and uninterrupted functioning. This *safety, security & privacy* category generated 64 quotes during the coding process, making it the category with the second fewest codes compared to all other categories. Security & safety was investigated in 17 out of 34 articles (50 %), data privacy in just 10 articles (29 %) as documented in Table 3.

3.4.1. Safety & security

This review categorizes security & safety concerns into three critical areas for SAVs: infrastructure security, which guards against physical and cyber threats; communications security, ensuring data integrity and flow; and reliability and emergency management, preparing SAVs for crisis situations (Fagnant & Kockelman, 2015; Khan et al., 2019; Stephanedes et al., 2019). Communication security focuses on deploying network and data protection (e.g. encryption, firewall technology) from interference, such as jamming and hacking, to assure the uninterrupted transmission of information (Jiang et al., 2022; Sheehan et al., 2019). Reliability and emergency management tries to mitigate risks from edge cases, difficult situations, and disruptions, such as natural disasters, to quickly recover and maintain secure functionality in critical situations (Khan et al., 2019). The use of redundant systems and disaster recovery plans are exemplary implementations for system reliability and emergency management. Physical attacks could disrupt SAVs' sensory equipment, while cyber-attacks might compromise data integrity, both posing serious risks to operational safety and privacy. Thus, attacks can be acts of espionage (e.g. gaining unauthorized access to infrastructure-related systems) or acts of sabotage (e.g. physically accessing a sensor and actively compromising its operation) (Fagnant & Kockelman, 2015; Saeed, 2019). Successfully exploiting a system's vulnerabilities and disrupting its operation requires a more sophisticated physical attack, which fortunately is limited to a single vehicle (Sheehan et al., 2019). Furthermore, hacking and jamming can be the trigger for communication and network threats (e.g. roadside communication devices, internet access) (Jiang et al., 2022). SAVs will mostly rely wireless communication with other vehicles and optionally infrastructure, making hacking of these V2V, V2I, or V2X devices fatal (Khan et al., 2019). Finally, Khan et al. (2019) present that a city's CAV readiness must take into account its ability to recover from disasters. In situations where something goes wrong, a city must be able to respond to disasters or security threats. The handling and prevention of crashes, the safety of the vehicle itself as well as the overall safety of all vehicles are also partly covered by this code. Overall, the ability of a city is also highly relevant for SAVs in order to ensure a reliable service quality and, more importantly, service safety.

3.4.2. Data privacy

Despite the proliferation of digital and smart products, data privacy concerns remain prevalent (Fagnant & Kockelman, 2015). This is also true when SAVs, and therewith AVs and sharing, become mainstream. Hereby, it is essential to distinguish between personal data privacy (e.g. when booking the service via an app) and vehicle data privacy (e.g. video surveillance in the vehicles) (Fagnant & Kockelman, 2015; Kimley-Horn, 2016; Stephanedes et al., 2019). The potential access of government authorities to store vehicle or personal data, especially through continuous surveillance, raises significant privacy controversies (Fagnant & Kockelman, 2015). To prevent the misuse of personal data by government authorities and employees, adequate security measures and regulations must be followed. However, in a scenario where SAVs are widely used, it is indispensable that large amounts of personal information and vehicle data are recorded, such as during the app registration process, data generated by sensors at the vehicle, location data, remote access, vehicle condition, multimedia screens, among more (Fagnant & Kockelman, 2015; Stephanedes et al., 2019). While the widespread use of SAVs necessitates recording extensive personal and vehicle data, balancing this need with stringent data privacy protections is fundamental. Although, most of the data is necessary for emergency response and roadside assistance, it is imperative that customers are clearly informed about how and with whom their data is shared (Stephanedes et al., 2019). This also includes that third party companies will adhere to all coherent security and privacy requirements of the original vendor at all times (Stephanedes et al., 2019).

The technology transition theory by Geels (2002) for the crucial category of *safety, security & privacy* related challenges suggests to follow a similar path to the two previously described categories, with novel configurations at the micro level (e.g. communication security, infrastructure security) to be applied to the landscape (macro level), which could further ensure homogeneity across different jurisdictions (regional, national, international).

3.5. Customers & citizens

For all disruptive technologies, customers and citizens, as the primary users, must be willing to use and adopt such a new innovation, whether it is a product or a service. The same is true for SAV services. To successfully implement SAVs in cities, the users must be willing to use such services and possess the necessary knowledge and skills (Greifenstein, 2024; Kimley-Horn, 2016; Narayanan et al., 2020; Threlfall, 2020). This requires clear understanding on SAV operation, their safety and efficiency benefits, potential cybersecurity challenges, and the importance of awareness and education programs (Alessandrini et al., 2015; Barnes & Turkel, 2017; Duarte & Ratti, 2018; Jiang et al., 2022). This category *customer & citizens* has gotten just 61 quotes during the coding process, making it the category with the fewest codes compared to all other categories, while over half of the articles (20 out of 34; 59 %) included have investigated its subcategory citizen readiness (see Table 3).

The study by Jiang et al. (2022) highlights that citizens need to be willing to use new mobility offering such as CAVs. They also mention that citizens need to be equipped with a certain knowledge and skillset to successfully adopt such new mobility systems (Jiang et al., 2022). On the one hand, citizens need the education and skills (e.g. digital affinity to use apps, book trips online) while also be capable of doing so (e.g. possessing a smartphone) as well as being informed about the services themselves, including their features and functionalities (Barnes & Turkel, 2017; Jiang et al., 2022). On the other hand, there needs to be a willingness of citizens to use and accept SAVs (Greifenstein, 2024), which can also be facilitated by public authorities and operators to encourage adoption, for example through targeted communication, marketing or incentives. Hereby, research has shown that people with certain socio-demographics or mobility behavior-related factors are more likely to adopt SAVs. For example, younger individuals, tech-savvy populations, and those with a higher usage frequency and experience of public transportation are more inclined to adopt SAVs (Golbabaei et al., 2020, 2022; Greifenstein, 2024). While Threlfall (2020) further emphasizes "living near test areas" as a positive factor for acceptance, Greifenstein (2024)) shows no effect in its systematic literature review for that specific factor. Nevertheless, Threlfall (2020) uses technology use of society, consumer ICT adoption and digital skills as well as online ride-hailing data to measure the consumer acceptance for AVs. Lastly, Taiebat et al. (2018) points out that travel patterns/ habits as well as having the ability to change such travel patterns/ habits plays a pivotal factor with the biggest environmental impact. In summary, the literature emphasizes the importance of user behavior in general when introducing new mobility services such as SAVs. Addressing the willingness, intention, acceptance, lifestyle benefits (e.g. beneficial travel patterns), and knowledge and skills is essential for the adoption of SAVs in urban environments.

To shift customers perceptions from patterns such as reluctance to rideshare, distrust in AVs, or car-centric cultural habits with the long-standing norm of private car ownership, to less regime-level cultural resistance to SAV adoption, cities can actively engage by familiarising a small segment of the public with SAVs (e.g., free trials, educational advertising, building trust in the technology). This would be in line with the dynamic multi-perspective of Geels (2002) transition theory to simultaneously work with the cultural context of the current regime while cultivating, educating and familiarising the niche SAV innovation, all under the influence of landscape changes such as demographic shifts.

The entire third chapter synthesizes the key findings of the integrative literature reviews by developing and presenting a conceptual framework that delineates how cities can proactively prepare for the integration of SAVs. The resultant conceptual framework (see Fig. 1) provides a consolidated overview of all the findings and offers a structured approach for cities to navigate the complexities associated with the deployment of SAVs.

4. Discussion

The results of the integrative literature review provide valuable insights into the multifaceted implementation challenges associated with the successful integration of SAVs in urban environments. The findings underscore the importance of addressing various aspects, including infrastructure adaptations, regulatory frameworks, technological innovation, the required collaboration of various stakeholders and economic commitment, safety and security measures, and citizen engagement, to ensure city readiness for the successful deployment of SAVs. This discussion will explore the implications and significance of the key findings within each category.

As this review shows, the focus of most publications so far has been on the physical and digital infrastructure challenges to the efficient operation of SAVs (e.g., Barnes & Turkel, 2017; Tengilimoglu et al., 2024a, 2024b). There is a need for improvements and adaptations to the existing physical infrastructure, including road conditions, structures such as bridges or tunnels, and high-tech roadside facilities such as mobility hubs, parking, and charging (e.g., Fagnant & Kockelman, 2015; Jiang et al., 2022; Khan et al., 2019). These improvements are necessary to ensure the safety and efficiency of SAV operations. For example, cities and regions can ensure that road lines are well visible, and that the overall road infrastructure is well maintained, in good condition and digitised where appropriate. For certain critical intersections or road designs, cities, such as Oslo or Hamburg with clear commitments towards SAV implementations until 2030, can work together with operators and technology providers to ensure that these critical areas are recognised, and solutions are found (e.g. excluding these sections from the operational design domain or improving them with V2X communications and smart sensors). More specifically, policy measures could include mandated infrastructure audits to identify SAV-readiness gaps, subsidies or tax incentives for infrastructure modernization, or the

establishment of urban test regions in selected areas to allow for wide-scale pilots and refine AV-friendly street designs. In addition, a robust and reliable digital infrastructure, including cyber network availability and data analytics, is required to enable seamless data transmission between SAVs and their environment (including V2I, V2V, and V2X). Private or public sector investment in digital infrastructure upgrades (e.g. ubiquitous 4 G or even 5 G network coverage) is emerging as a fundamental prerequisite for the successful deployment of SAVs (e.g., INRIX, 2017; Kovács & Lukovics, 2024; NACTO, 2017). Public-private partnerships are essential to identify and manage critical dead spots and, for example, major events that could affect SAVs and their interaction within cities.

Public policy and the regulatory landscape also play a central role in enabling the emergence of SAVs. Policymakers need to redesign existing regulations and processes to accommodate autonomous vehicles, including licensing, liability issues, safety standards, and vehicle homologation ideally in a highly standardised manner (e.g., Alawadhi et al., 2020a; Jiang et al., 2022; Johnson, 2017). For instance, a major upcoming milestone will be obtaining vehicle homologation for Level 4 autonomy for robo-taxis such as those developed by Waymo or Zoox as well as real-time regulatory feedback and iterative adaptations of approval processes, which would pave the way for scaling up fleet operations. Moreover, policies can incentivise shared transport modes to promote sustainability and equitable access to SAVs. This could include congestion pricing for private vehicles alongside discounted or subsidised SAV fares in urban areas, or mandatory fleet-sharing ratios to ensure SAVs are not operated as private vehicles by proxy. Multi-stakeholder collaboration is essential for policymakers and the public sector to develop comprehensive regulatory frameworks, preferably at national or even international level, as well as standardised safety, licensing, and homologation processes.

The emergence of SAVs presents significant economic opportunities, ranging from technological innovation to new business models, collaborative ventures, and different pricing and profitability strategies. Technological advances in autonomous vehicle technology (e.g. sensors, connected vehicle technology) allow private companies to drive innovation and develop new business models and components that enable SAVs in cities (e.g., Duvall et al., 2019; Mares et al., 2018; Threlfall, 2020). However, collaboration and partnerships, not only by private companies but also by the public sector, are essential to take advantage of these economic opportunities arising from the emergence of SAV operations. As there are not many publications that focus on this category, such economic opportunities are probably not yet interesting enough to be investigated extensively. Nevertheless, it is of great importance as the exacerbating funding gap (e.g. transition to electric vehicles, digital mobility services, infrastructure investment backlog) will continue to increase with the deployment of SAVs and consequently the high investments needed in infrastructure and related services. To address this, cities could explore co-financing mechanisms, such as toll roads, congestion charge or infrastructure usage revenues reinvested into AV programs, public innovation funds to support local AV-related businesses or other revenue streams (e.g. parking, pick-up and drop-off fees) to push SAVs. Therefore, it is crucial to further deepen the understanding of the economics of SAV deployments and their implications for scalable deployment, as well as the overall investments required, by discussing different funding schemes or budgeting strategies for the public sector and equivalent.

As SAVs rely heavily on the collection, analysis, processing, and transmission of data, ensuring robust security and safety measures is paramount to secure operations (e.g., Dokic et al., 2015; Gavanas, 2024; Saeed, 2019). The review underscores the need for comprehensive security protocols to mitigate physical and cyber threats. Measures such as end-to-end encryption, real-time threat monitoring, and disaster recovery plans are important to protect SAV operations from potential security breaches and ensure uninterrupted operations. Furthermore, addressing data privacy concerns will increase public trust and confidence in SAV operations, which should be considered by operators. However, literature on this category is scarce, which indicates that it has not yet been extensively researched, either because it is not yet attractive enough or because existing research is sufficient to understand what cities need to prepare for, and hence the category itself simply has a lower degree of relevance and importance. Nonetheless, cities could proactively introduce cybersecurity standards for all connected mobility systems, similar to the ISO/SAE 21434 standard for road vehicles, and mandate public disclosure of anonymized incident data to foster transparency and learnings across jurisdictions of different countries and continents.

Lastly, the successful integration of SAVs depends on user acceptance and adoption. Educating society about the benefits, (safety) features, and operational aspects of SAVs is key to enhancing acceptance and overcoming potential resistance barriers. The adoption trajectory of SAVs is likely to vary across cities, regions and countries due to socio-cultural attitudes, habits among more, which should also be taken into account when tailoring policies and measures by identifying local needs and structures. For example, cities with higher digital skills and technology openness, such as San Francisco, Stockholm or Oslo, may find it easier to introduce SAVs via mobile-based apps, while others might struggle more. To ensure that these new mobility solutions are inclusive, it is necessary to provide equitable access to SAV services and to address socio-demographic disparities in adoption rates. This category has the lowest number of coded quotes, which may indicate that cities do not (yet) see the need to prepare their citizens for the deployment of SAVs potentially because they assume that citizens will use them without hesitating once services are available. Nevertheless, concrete policy measures could include targeted education campaigns for older or less tech-savvy populations, subsidized fares for low-income users, and routing strategies that prioritise underserved und unprivileged areas.

5. Conclusion and limitations

This integrative literature review examined and synthesized existing research in the field of AVs, CAVs, and SAVs. Using a qualitative coding procedure following Strauss and Corbin (1998)), this review identified categories of requirements that will enable the successful implementation of SAVs in cities and urban areas. The results show that, overall, infrastructure, policy, regulation & legality, economic opportunity, security & privacy, and customer/citizen are the core categories. Therefore, the novelty of this research lies in the development of a conceptual framework that discovers these core categories and relevant subcategories, while filling the previously described practical-knowledge gap as defined by Miles (2017), as well as partly following the socio-technical transition theory of Geels (2002) for conceptualisation.

Cities and authorities can build on the proposed conceptual framework to prepare for the successful implementation of commercially viable SAVs. For example, by investing and ensuring sufficient physical and digital infrastructure such as good road conditions, smart infrastructure (e.g. V2X, dynamic curbside management, smart parking management) continuous network availability and sufficient data analytics capabilities, cities can ensure a high level of readiness for SAVs. Policymakers, regulators, and authorities need to provide incentives or privileges for SAVs (e.g. incentives, subsidies, grants, funds), consistent approval and certification procedures (e.g. standardized licensing process, liability frameworks, insurance policies tailored to SAVs), and sensible infrastructure and vehicle regulations. In order to educate citizens for increasing usage intentions, public authorities and operators/private providers need to work together to communicate, inform and educate their potential customers. Future research can provide empirical validation of the proposed conceptual framework and, in particular, deepen the understanding of each of the codes and sub-categories for which work has already started in some areas, such as parking management for SAVs (e.g. Hu et al., 2024; Jin & Ma, 2024; Zhang et al., 2015).

Furthermore, on a theoretical level, this conceptual framework can be further used to iteratively develop theory or strengthen it by applying more theoretically driven approaches, such as fully following the socio-technical transition theory by Geels (2002), the smart city framework by Giffinger et al. (2007), the triple helix model of innovation by Etzkowitz and Leydesdorff (1995) and Carayannis and Campbell (2009) or the adapted living labs approach by Schuurman (2015) and previous scholars, as first commercial and fully autonomous services can now already be found in California, USA.

This integrative literature review has several limitations that should be kept in mind. The selection of keywords, search string, and databases used limit the significance of the work to SAVs and city readiness for SAVs. After the initial search, the authors included more specific aspects of readiness as keywords (e.g., infrastructure, policy) during the cross-reference checks of the reference lists of the included papers, which broadened the scope and led to the identification of additional grey literature. Since the database searches were conducted at the end of April 2025, this review – like most reviews – also holds a time limitation; more recent literature that may have raised additional issues was not considered due to this time limitation. Furthermore, relevant literature may be missing due to the exclusion criteria. As the search and screening of publications was carried out by the first author, the process may have been biased. However, the data analysis process and the development of the conceptual framework were discussed by all authors. Although the data analysis was performed with care, this review cannot guarantee that no errors were made.

Due to the scarcity of academic literature on the topic, grey literature (non-peer reviewed articles, reports, book chapter) cited in the eligible studies was considered at the cross-reference check, resulting in a strong focus on non-peer-reviewed articles and whitepapers. Since the peer-reviewed articles used in this review were mainly published in transport-related journals and conferences, the results need to be considered in this context, while emphasising that research needs to be extended to other areas, such as environmental journals, to provide more robust propositions on how to prepare cities efficiently for SAVs. Furthermore, future research needs to focus on whether the conceptual framework with its categories and subcategories developed and derived from academic and grey literature, is congruent with today's practice perspective. The reported number of coded quotes for each category does not indicate its importance. Therefore, future research needs to further explore the relevance and importance of each category, subcategory, and code for the implementation of SAVs. Furthermore, this review primarily focuses on a global perspective of city readiness for SAV. Future research should examine adoption potential, regulatory and policy frameworks, economic structures, and socio-cultural attitudes and impacts at a regional level, as these factors, as well as behavioural incentives and potential resistance factors on user willingness to adopt SAV, may vary widely from local to regional levels and between different geographies. In addition to geographical differences, differences between densely populated metropolitan areas and suburban areas need to be investigated, as metropolitan areas may benefit from SAV as a last-mile solution to public transport, whereas suburban and rural areas may require hybrid models that integrate SAV with private transport. Future research could also deepen the understanding of how to use artificial intelligence and Internet of Things (IoT)-enabled smart infrastructure and services to improve SAV and adoption. Therefore, city readiness must extend beyond static changes and encompass adaptive ecosystem variations that support future mobility solutions.

Author agreement statement

I, the undersigned, declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

I confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. I further confirm that the order of authors listed in the manuscript has been approved by all.

I understand that the Corresponding Author is the sole contact for the Editorial process. I am responsible for communicating about progress, submissions of revisions and final approval of proofs.

CRediT authorship contribution statement

Marvin Greifenstein: Writing – original draft, Visualization, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Alessandro La Delfa:** Writing – review & editing, Visualization, Formal analysis. **Zheng Han:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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