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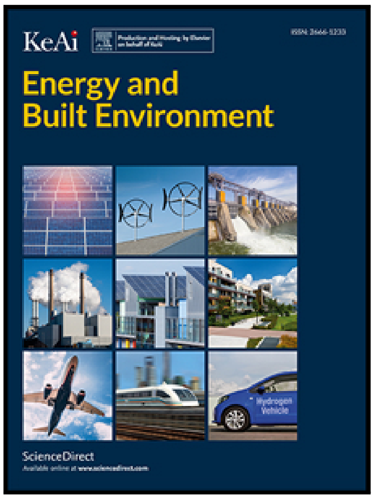

Future cities and autonomous vehicles: analysis of the barriers to full adoption

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Highlights:

- Identify Autonomous vehicles barriers will help to promote their adoption
- Safety, users' acceptance and behaviour are the predominant barriers of AVs
- Distrust feelings and perception affect people to adopt Autonomous vehicles
- Large scale tests of Autonomous vehicles will facilitate their deployment
- All barriers' expected solutions will change our cities and the built environment

Future cities and autonomous vehicles: analysis of the barriers to full adoption

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Abstract

The inevitable upcoming technology of autonomous vehicles (AVs) will affect our cities and several aspects of our lives. The widespread adoption of AVs repose at crossing distinct barriers that prevent their full adoption. This paper presents a critical review of recent debates about AVs and analyse the key barriers to their full adoption. This study has employed a mixed research methodology on a selected database of recently published research works. Thus, the outcomes of this review integrate the barriers into two main categories; (1) User/Government perspectives that include (i) Users' acceptance and behaviour, (ii) Safety, and (iii) Legislation. (2) Information and Communication Technologies (ICT) which include (i) Computer software and hardware, (ii) Communication systems V2X, and (iii) accurate positioning and mapping. Furthermore, a framework of barriers and their relations to AVs system architecture has been suggested to support future research and technology development.

Keywords

autonomous vehicles; smart city; barriers; safety; technology; users' behaviour

1. Introduction

The world is witnessing the Fourth Industrial Revolution (FIR) that is characterized by combining digital, physical and biological worlds. [1] argues that this era is marked by several breakthroughs in advanced technologies such as artificial intelligence (AI), Robotics, quantum computing, Internet of Things (IoT) and fifth-generation wireless technologies (5G). FIR is also known as "Industry 4.0" [2]. On the other hand, Climate change, population growth, transportation, international security issues, and globalisation are the main challenges for future urban development [3]. Therefore, the right assembly of emerging technologies, components, skills, and needs can deliver smart/future city objectives [4]. Examples of these objectives are developing or generating new services, a delicacy of management, smart infrastructure, sustainability and facilitating planning.

The most crucial application of integrating the digital and physical worlds are Automated Driving (AD) and Connected Autonomous Vehicles (CAVs) [5,6]. The former will give rise to new mobility concepts and opportunities as well as it will expand the transport system capacity and efficiency. These technologies will radically change the transportation infrastructure and will impact future planning. The adoption of AVs in future/smart cities is associated with many potential benefits. However, from analysing existing literature, it has been noted that many scholars place a high emphasis on safety. This aspect is usually addressed in line with the National Highway Traffic Safety Administration (NHTSA) report, which in turn suggests the use of "highly effective crash avoidance technologies" to prevent crashes [7]. This criterion implies that AVs driving systems must be as robust as aviation standards [8]. It is crucial to go through different types and levels of automation to understand how autonomous cars will perform and behave. The more computers are doing the level of assistance provided by machines, the fewer humans' intervention, and the more functions, the more automated level is becoming higher. Hence, Table 1 illustrates the five levels of automation suggested by the NHTSA. These levels range from no input from machines which is level 0 to full automation which is level 4.

Table 1. NHTSA's levels of Vehicle Automation reproduced from [7]

Level 0	**No-Automation**
Level 1	Function-specific Automation
Level 2	Combined Function Automation
Level 3	Limited Self-Driving Automation
Level 4	Full Self-Driving Automation

It is anticipated that AVs will increase safety and comfort [7,9], and reduce traffic congestions, pollution, fuel consumption, as well as facilitate further the mobility accessibility to disable and older people. Also, self-driving will decrease the number of accidents and crashes through the vehicle to vehicle communication [8,10]. Besides safety, several scholars have discussed further in prospect benefits of adopting AVs, as shown in Table 2. [11] argues that since internet emergence, AVs will be the most substantial change and transition that will happen to societies and cities.

Table 2. Anticipated benefits found in the literature of AVs.

Anticipated AVs' Benefits	**Studies**
Innovative freight delivery	Alessandrini et al. [12]
Insurance cost reduction	Agarwal, Kumar and Zimmerman [13] Wadud [14]

Efficiency of road transport and a number of service categories	Alfonso et al. [15]
Control of traffic flow	Liu et al. [16] Stern et al. [17]
Maximize intersection capacity and minimise its bottlenecks	Sun, Zheng and Liu [18]
Comfort and entertainment services	Atzori et al. [19] Panagiotopoulos and Dimitrakopoulos [20]
Reduced congestions and increased accessibility	Joiner [21] The House of Lords Science and Technology Committee [22]
Energy efficiency	Vahidi and Sciarretta [23]
Fuel consumption reduction through platooning and “Right-sizing” of vehicles	Simoni et al. [24] Vahidi and Sciarretta [23] Zhao et al. [25] Wadud, MacKenzie and Leiby [26]
Make travelling by car more attractive	Gruel and Stanford [27]
Offer mobility to people unable to drive	Alessandrini et al. [12] Fagnant and Kockelman [10]
Tourism extension	Cohen and Hopkins [28]
Economic and social	Bechtsis et al. [29] Bichiou and Rakha [30]
Expand new markets and more software and hardware companies to be developed	Bamonte [31]
Travel speed increase	Kröger, Kuhnimhof and Trommer [32]

As AVs will bring several benefits, it could also be associated with several potential risks. For example, the digitisation of the transport system can be vulnerable to hacking [15,19,33]. Furthermore, [12,13,34] claim that AVs could be exposed to system failure. Another hazard that can be linked to AVs is malicious cyberattacks through a non-trusted network [34]. Not only risks are cybernetically related, but also other hazards can be associated with AVs such as using both modes of driving (Manual and automated) can lead to miscommunication [35].

Extensive research is being conducted on AVs and their potential effects on many aspects of our lives. However, access to these benefits will have to overcome several obstacles. Many researchers have addressed these obstacles, and some have suggested several solutions to surpass AVs holdbacks. Table 3 summarises the selected reviews that discussed the most critical problems facing AVs based on their date of publication and number of citations. Interestingly, most of these problems are related to technology and users’ behaviour. For example, we find that many scholars have focused more on technological and technical issues studying vehicular communications, and sensors technologies. Starting from the principle that they come to the most important barrier that must be overcome. At the same time, but to a lesser extent, some reviews have pointed out other obstacles, especially in the study of behaviour and to what extent people accept this new technology. Based on the above, this review attempts to integrate all the obstacles discussed by the previous studies. Thus, the purpose of this review is not only to determine these obstacles but to employ a mixed research method to extract other barriers and study the extent of their overlap.

Table 3. Summary of selected reviews about AVs and related subjects (citations till April 2020).

Study/year		**Aim of the study**	**Subject**	**Citations**	**References**
2019	Gkartzonikas and Gkritza [36]	To examine the individuals behavioural, perceptions and willingness to use AVs	AVs and users' acceptance	51	50
	Faisal et al. [37]	Suggest a framework to advocate the urge of preparing cities to adopt AVs	AVs impacts, planning and policies	26	144
	Pearre and Ribberink [38]	Understand current concepts on V2X technologies	Vehicular communication	19	70
	Cui et al. [39]	Explore the recent research about AVs safety and security attacks.	AVs Safety	15	167
	Stead and Vaddadi [40]	Explore how AVs can transform urbanisation patterns and affect urban forms.	AVs and urban impacts	12	37
	Iskander et al. [41]	Explore various theories about motion sickness and its applicability to AVs.	AVs and Users' Comfort	06	77
2018	Yang and Pun-Cheng [42]	Examine various vehicle detection approaches considering several environments	Vision computing Machine learning	39	123
	Duarte and Ratti [43]	Investigate the impacts of AVs on cities and urban life.	AVs and cities	36	61
	Abbasi and Shahid Khan [44]	Investigate V2V communication protocols in urban environments.	Vehicular communication VANETs	17	33
	Campbell et al. [45]	Examine the required sensor technologies for an AV.	Sensors technologies	09	22

	Meinlschmidt, Stalujanis and Tegethoff [46]	Investigate the psychobiology of using automated driving	AVs and the psychobiology	03	46
2017	Milakis, van Arem and van Wee [47]	Explore the implications of automated driving on policy and society.	Social and Policies	271	162
2016	Richards and Stedmon [48]	Highlights the important key human factors linked between users and AVs systems	AVs and users' reaction and interaction	32	32

It is crucial to understand how these emerging technologies can be managed and tackle their challenges. Precisely, to achieve AVs benefits, we must start planning, deploying policies and realise their advantages and disadvantages [49]. Therefore, it is evident that the adoption of AVs could have many advantages, and it is impractical to attain such benefits without understanding and tackling different barriers/ obstacles associated with its approval. In other words, to understand and evaluate the effects and changes that AVs can cause in our cities, it is imperative to explore and comprehend firstly, the mechanism of how an AV works (Vehicle specifications) or what is called "Autonomous vehicle system architecture". Secondly, identify the various barriers that restrain the adoption of these technologies because this will help to define the required infrastructures that ensure the smooth performance and safety of AVs.

Although there exists a considerable amount of work addressing the potential benefits, barriers and risks of AVs, there is no study that has reviewed all obstacles of AVs in one review. For those reasons, this paper aims to examine various barriers and challenges to the AVs implementation, meanwhile studying their interrelatedness. Also, this study suggests a developed conceptual framework showing the AVs system architecture and how the possible obstacles are linked to it. Furthermore, the proposed framework of this study considers the highest automation level, which is Level 4 (Full Self-Driving Automation) Table 1.

The review is structured into four sections. Firstly, section 1 discusses the background of the subject highlighting the benefits and risks of AVs as well as the focus of existing research. Secondly, section 2 outlines the research methodology applied to achieve the aim of this review which is a mixed-methods research methodology. Thirdly, section 3 presents the findings of the study and combines the barriers to full adoption into two main groups. Finally, section 4 summarises the findings and proposes a framework assembling the barriers that are needed to overcome linked to AVs 'system architecture.

2. Methodology

This paper critically reviews the state of the art of literature about AVs, where more than 82% of the selected papers were published since 2017. The focus is on papers that refer to issues and obstacles that AVs are currently facing. Besides, this paper considers various source types of publications, such as journal articles, books, book sections, reports, and conference proceedings, see Figure 1. However, about 72% of the sources are journal articles. This systematic review followed a technique of classification employing the taxonomy approach, which is more empirical, as described by [50].

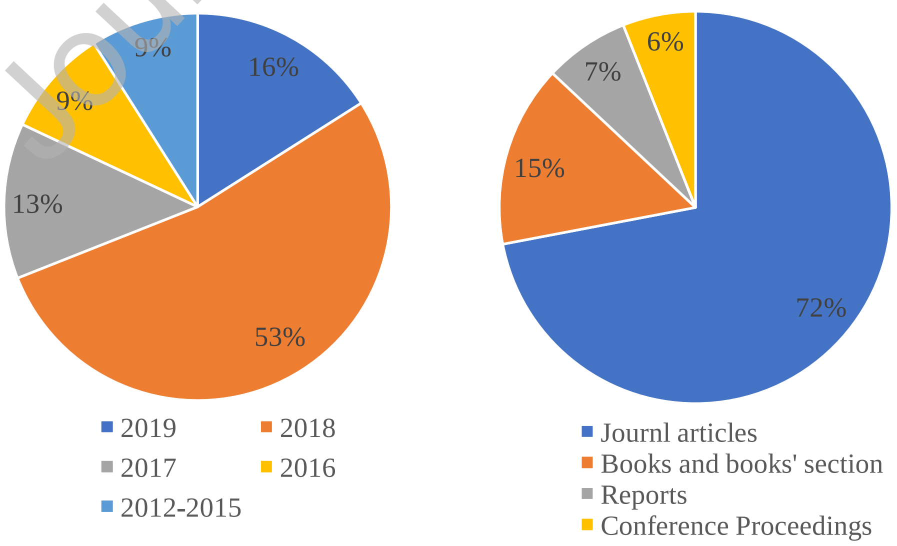

Figure 1. Types and publication date of the Sources analysed.

Figure 2 represents the methodology diagram used in this study to answer the research question, which is a mix-methods research methodology that is composed of four stages. The Figure also demonstrates how the four stages were performed consecutively and whether they are quantitative or qualitative.

The first stage we began by building a database of papers, firstly, the search was conducted by including words related to Autonomous vehicles such as driverless and self-driving vehicles. This search was proceeded on various online databases, i.e., ScienceDirect, Web of Science, Scopus, Google Scholar and ResearchGate. Secondly, an in-depth analysis of abstracts and relatedness of 400 papers was carried out, which led to select 140 sources. Four stages have been performed to address the aim of this paper.

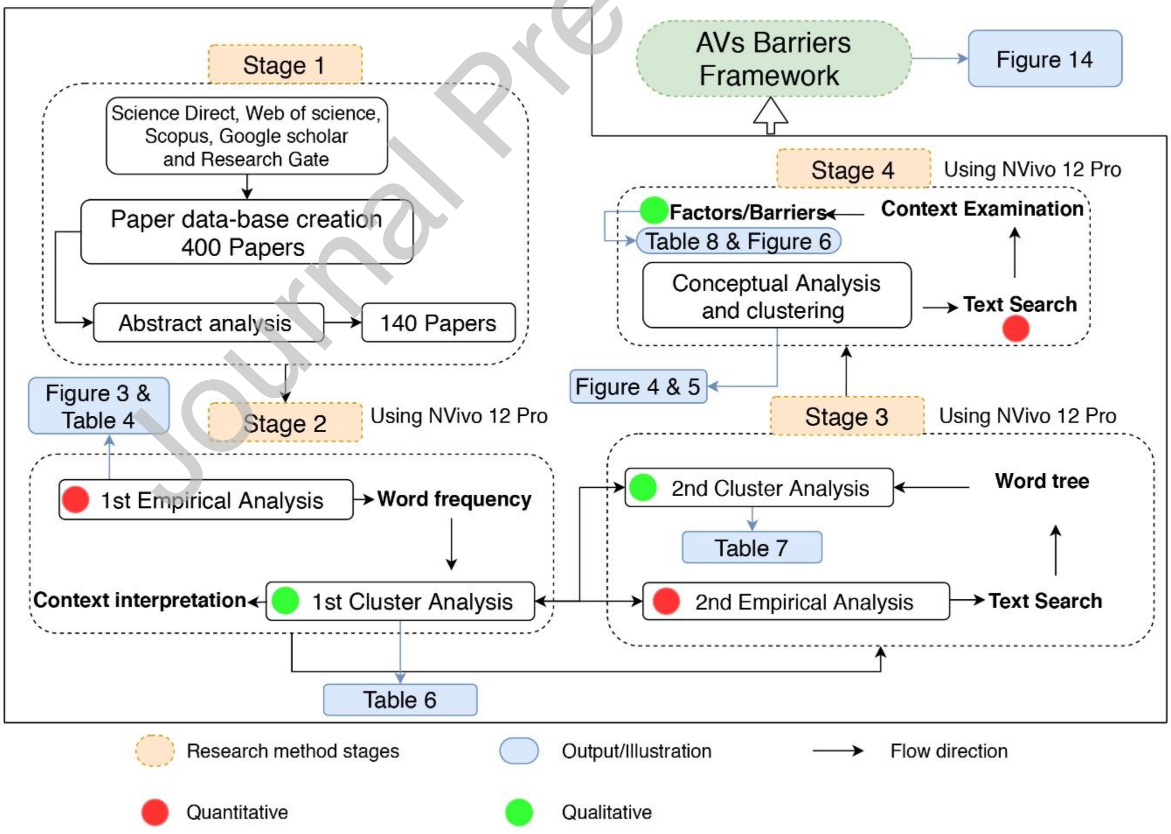

Figure 2. The methodology flowchart undertaken for this study

The second stage consists of two phases; (1) the empirical analysis is done using the software NVivo 12 Pro by employing the word frequency function on the selected sources looking for words with four letters minimum length. The grouping criteria to measure the similarity level is set to exact matches. Table 4 and Figure 3 illustrate the most frequented words and their weighted percentage obtained from the second stage.

Figure 3. Word cloud showing the 40 frequented words.

Table 4. Word frequency and their weighted percentage.

Word	Count	Weighted Percentage (%)
data	3871	0.44
time	3865	0.44
control	3116	0.35
technology	2736	0.31
safety	2564	0.29
information	2389	0.27
public	1818	0.21
liability	1765	0.20
traffic	1717	0.19
travel	1709	0.19
network	1628	0.18
mobility	1604	0.18
future	1448	0.16
human	1424	0.16
urban	1402	0.16

speed	1267	0.14
lane	1258	0.14
communication	1243	0.14
planning	1234	0.14
cost	1124	0.13
services	1101	0.12
connected	1099	0.12
policy	1096	0.12
intelligent	1062	0.12
risk	1043	0.12
demand	1040	0.12
market	1039	0.12
software	1007	0.11
environment	984	0.11
users	950	0.11
sharing	922	0.10
people	887	0.10
simulation	825	0.09
detection	817	0.09
privacy	815	0.09
energy	813	0.09
test	808	0.09
insurance	794	0.09
social	794	0.09
infrastructure	740	0.08

Then, (2) Cluster analysis of the generated concepts from the word frequency (Table 4). The former is done by analysing their context intensively in the papers to cluster them in several groups based on their possible context interpretation. The analysis indicated that the concepts can be classified into four groups. For instance, the word "Data" is found that its interpretations been linked to being technical, social and legislative. Table 5 illustrates examples of how the context of "data" is associated with different interpretations. Following the same method, Table 6 summarises the four clusters generated from the analysis of the entire words listed in Table 4, where the symbol (X) indicates the association of the concept with the cluster.

Table 5. Example of context analysis of the word Data and its association.

Context	Source	Interpretation
"Data Fusion (DF) presents a key point in road safety applications"	Armingol et al. [51]	Technical
"willingness of end-users to give consent to broadcast data is not a barrier, in particular if the data is to be used to enhance road safety"	Alfonso et al. [15]	Social
"It is essential that any data gathered from CAV are used in accordance with data protection law"	The House of Lords Science and Technology Committee [22]	Legislative

Table 6. Concepts' clustering based on their context.

Word	Technical	Social	Urban	Legislative
data	x	x		X
time	X	X	X	
control	X	X		
technology	X	X	X	X
safety	X	X	X	X
information	X	X	X	X
public		X		X
liability	X	X		X
traffic	X	X	X	X
travel	X	X	X	X
network	X		X	X
mobility	X	X	X	X
future	X	X	X	X
human	X	X	X	X
urban			X	
speed	X	X	X	
lane			X	X
communication	X	X	X	X
planning		X	X	X
cost	X			X
services	X			
connected	X			X
policy		X		X
intelligent	X		X	
risk	X	X		X
demand		X		X
market	X	X	X	X
software	X			

environment	X	X	X	X
users		X		X
sharing	X	X	X	X
people	X			X
simulation	X			
detection	X			X
privacy	X	X	X	X
energy	X	X	X	X
test	X	X	X	X
insurance	X	X		X
social	X	X	X	X
infrastructure	X	X	X	X

The third stage is also a combination of two different phases; (1) an empirical analysis (2nd) using the software NVivo 12 Pro utilising the function “Text Search” instead of “word frequency” of the four clusters’ (Technical, social, Urban and legislative). The former phase is carried out on the papers’ database created at the beginning (stage 1). The second phase is analysing the former four clusters using Word tree function in NVivo. Figure 4 illustrates the legislation as an example of a word tree function output. Hence, Table 7 summarises the 2nd cluster analysis, where the outcome of this phase has also been grouped into two groups (Information and Communications Technology (ICT), and User/Government perspectives). The investigation was focusing on issues and obstacles that AVs are facing. Hence, the outcome of the three stages has revealed that the full adoption of AVs depends on various key barriers to overcome.

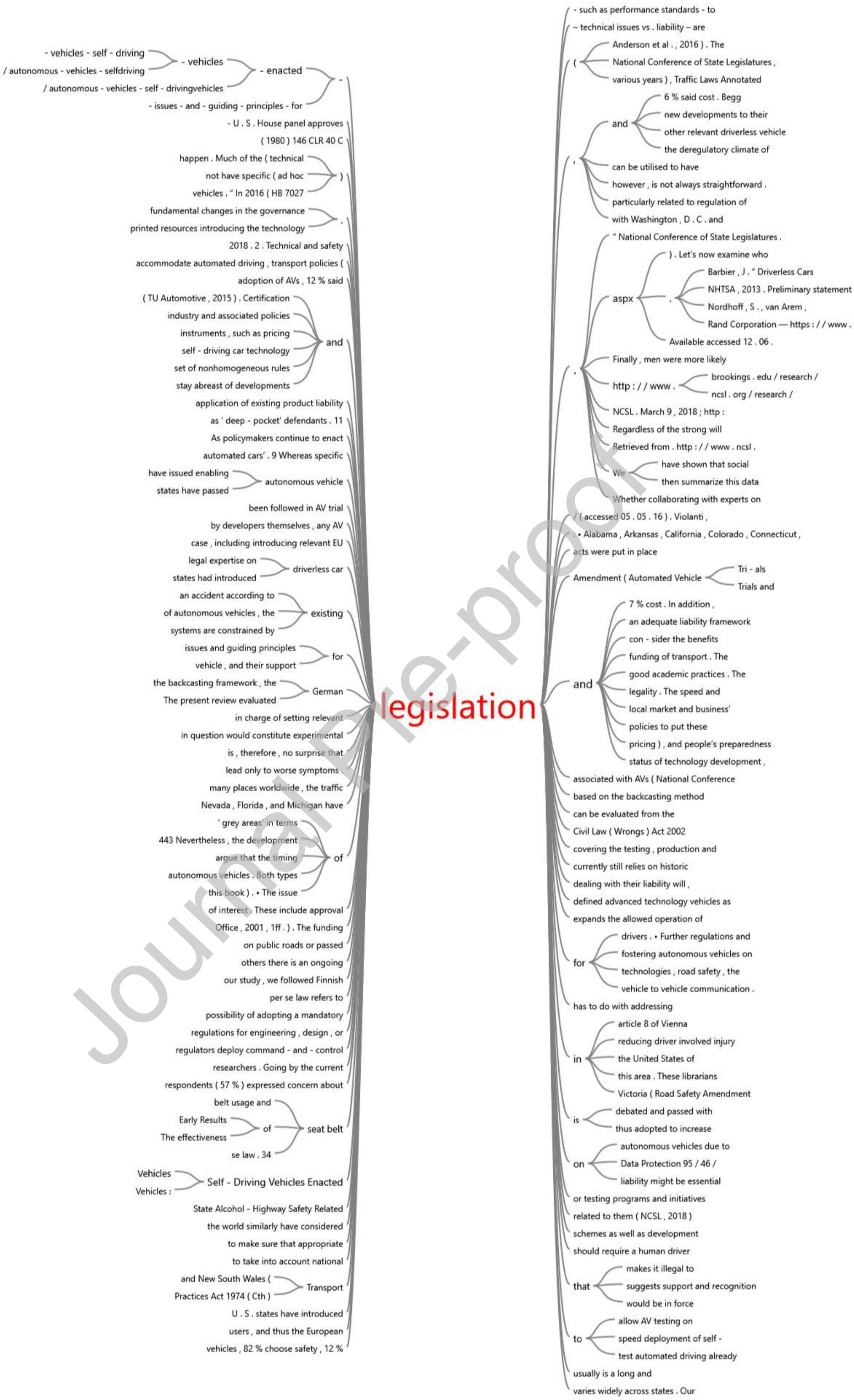

Figure 4. Example of a word tree function (Legislation).

Table 7. 2nd clustering based on the word tree of the 1st clustering analysis.

Technical 89 sources 353 count	**Social** 91 sources 908 count
Technology Vehicular Communication/Sensors Computer/network/simulation/Ad Hocs/VANETs Real-time control Human-Machine Interface Navigation/ Mapping/Positioning Safety Travel behaviour/forecasting/attitude Path reconstruction Certification/legal/policy/Law/liability/ Regulations// Standardizations Traffic management/performance Shareability Platooning Testing	Safety Sustainability Behaviour/Control/Change/Forecasting/Psychological perspectives/ perception Identity/Adoption/acceptance/Ownership Sharing systems/Norms/Participation/Trips Information/Data/Accessibility Ad Hocs /Networks/ Smartphones/technology/Navigation Benefits/Opportunities/ Failure/Attacks/Emergency Infrastructural factors/smart cities Economy/finance/cost/commercial Media/Politics/Government/Educational/Research Events/needs/ Employment/Independence/disability IoT/IoV/SIoV Activities/Recreations
Legislative 33 sources 112 count	**Urban** 109 sources 1306 count
Safety Pedestrian/Change Technical/ V2X communication/ Technology maturity Civil law Law Backcasting approach Liability/Standards/Guiding-principles/Policies/ Regulations/Funding transport Insurance Research/collaboration Market and businesses Experiments/testing Pricing/cost Data Protection	Safety/Regulation/Policies Planning/Infrastructure/Centre parking Cities/Rural/Regional/suburban/agglomerations/ sprawl/Dispersion/building/Trips/Commute/Mobility-models/Sharing/ travel-time/distance-travelled/ Cybernetic-Public-transport/Taxi/ Urban design/space morphology/ Urban-mobility/Traffic-Management/ Surface/roads/Street/crosswalk/intersection/ Highway/Expressway/roundabouts/Pathways/Nodes Environment/Tourism/Population/Geography/ Land/Location/landscape Accessibility/maintenance/charging stations/ Technology/Vehicular communication/ Network/Positioning/Simulation/GPS/smart servers/ Platooning Users/Privacy/Community/Sensors Services/Demand/density/congestion/footprint Testing
• Safety • Users’ acceptance and behaviour • Legislation	• Accurate positioning and mapping • Computer software and hardware • Communication systems

The final stage is a conceptual analysis of the barriers resulted from the previous three stages, with an examination goal that is set to explicit terms (Figure 4). This stage is also done using NVivo 12 Pro utilising the function "Text Search". For instance, searching the word "safety" in the papers' database disclosed that it is associated with 116 papers out of 140. The range of the word references occurrence was between 1 to 759. Thus, analysing the rest of the barriers illustrated in Figure 5 demonstrates that each obstacle is also tied up to other factors. An in-depth examination of all the barriers is discussed in section 3. Following the four stages discussed above, a framework of barriers that prevents full adoption of AVs is suggested, which also is linked to AVs system architecture.

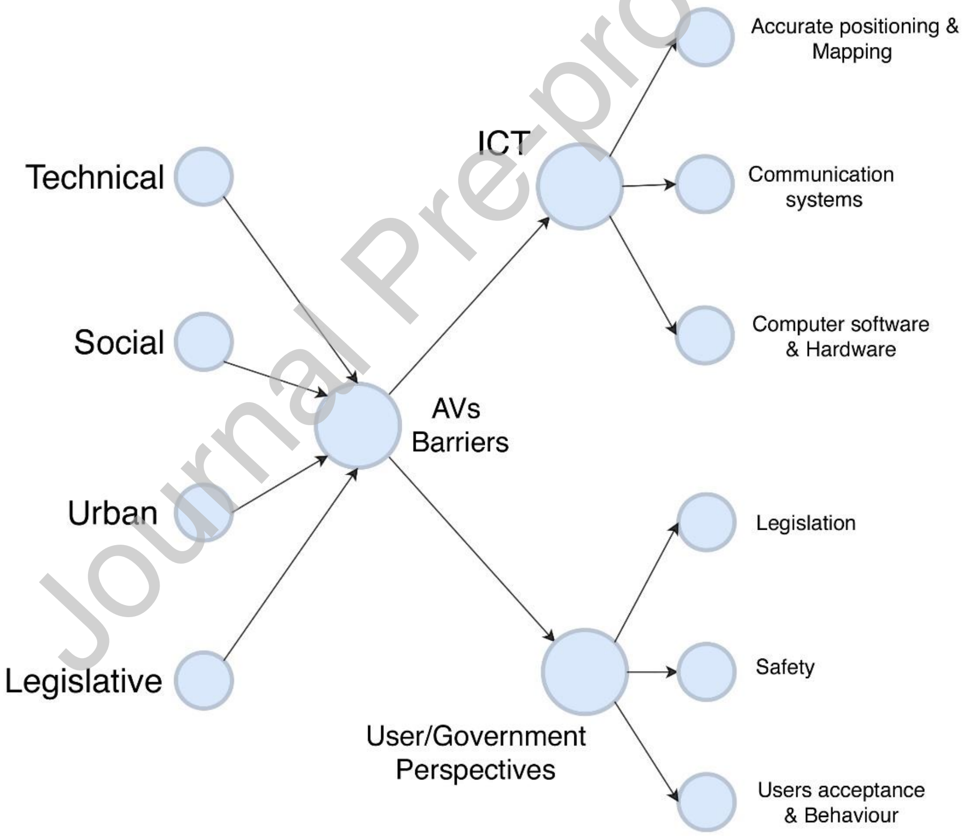

Figure 5. Key barriers preventing full adoption of AVs.

3. Key findings and discussions

This section presents a synthesis of the key findings that resulted from the four stages carried out on 140 papers published between 2012 and 2019, as illustrated in Table 8. The results of this study cluster the barriers into two main groups: ICT and User/Government perspectives. In turn, the formers are grouped into 6 sub-clusters, including the factors that contribute to each barrier as shown in Figure 6. Therefore, this section discusses in detail AVs barriers to full adoption.

In addition, each of the barriers shown in Figure 5 is explained with a diagram highlighting and clarifying the factors involved in the formation of each obstacle. Likewise, a synthesis of suggested solutions or actions is also shown in each diagram in the green boxes.

Table 8. Summary of the barriers and their related sources.

Barriers	Scholars		
	2019	2018	2012-2017
1. Safety	Ackermann et al. [52] Aguiléra [53] Combs et al. [54] Magnusson et al. [55]	Alessandrini, Holguin and Parent [56] Alfonso et al. [15] Armingol et al. [51] Department for Transport [57] Gopalswamy and Rathinam [58] Grush and Niles [59] Jiménez [60] Nazari, Noruzoliaee and Mohammadian [61] Simoni et al. [24] Skeete [62] Straub and Schaefer [35] Villagra et al. [63]	Alessandrini et al. [12] Bell [64] Fagnant and Kockelman [10] Fagnant and Kockelman [65] Francis [66] Kho, Abdulla and Yan [67] Litman [68] Maurer et al. [69] Perch [70] Roberts [71] Santi et al. [72] wsp [73]
2. User acceptance and reaction	Agarwal, Kumar and Zimmerman [13] Aguiléra [53] Alfonso et al. [15] Boutueil [74] Cohen and Hopkins [28] Combs et al. [54] Webb, Wilson and Kularatne [75]	Aarhaug and Olsen [76] Anania et al. [77] Buckley, Kaye and Pradhan [78] De Bruyne and Werbrouck [79] Ferrero et al. [80] Gheorghiu and Delhomme [81] Grush and Niles [82] Joiner [21] Kaur and Rampersad [33] Kim [34] Kolarova et al. [83] Liljamo, Liimatainen and Pöllänen [84] Meinlschmidt, Stalujanis and Tegethoff [46]	Alves [88] Babbar and Lyons [89] Bansal and Kockelman [90] Nath [91] Wadud [14] Bansal, Kockelman and Singh [92] Nordhoff, van Arem and Happee [93] Fagnant and Kockelman [10] Kyriakidis, Happee and de Winter [94]

			Molnar et al. [85] Winter et al. [86] Panagiotopoulos and Dimitrakopoulos [20] Straub and Schaefer [35] Xu et al. [87]	
3.	**Certification/regulations and ethics**	Narayanan [95]	Anania et al. [77] Bichiou and Rakha [30] Congressional Research Service [96] De Bruyne and Werbrouck [79] Kröger, Kuhnimhof and Trommer [32] Li et al. [97] López-Lambas [98] Noy, Shinar and Horrey [99] Ruggeri et al. [100] Straub and Schaefer [35] Evas et al. [101]	Chen et al. [102] Conceição, Correia and Tavares [103] Bonnefon, Shariff and Rahwan [104] Schellekens [105]
4.	**Accurate positioning and mapping**		Hongyu et al. [106] Konrad et al. [107]	Li et al. [108] Wang, Deng and Yin [109] Katrakazas et al. [110] Signifredi et al. [111] Kala and Warwick [112] Kim et al. [113] Zhang et al. [114] Levinson et al. [115] Chen and Fraichard [116]
5.	**Computer software and hardware**	Loukas et al. [117] Marletto [118] Xu and Duan [119]	Armingol et al. [51] Bechtsis et al. [29] Bichiou and Rakha [30] De La Torre, Rad and Choo [120] Guanetti, Kim and Borrelli [121] Marks [122] Mullins et al. [123] Noy, Shinar and Horrey [99]	Pendleton et al. [124] Sarikan, Ozbayoglu and Zilci [125] Wadud [14] Aria, Olstam and Schwietering [126] Kalra and Paddock [127] Maurer et al. [69] Tas et al. [128] Gallello [129] Kim *et al.* [113]
6.	**Communication Systems (Networks)**	Arena and Pau [130] Gao and Xin [131] Hou and Gao [132] Liu et al. [133] Rubin et al. [134] Rueckelt et al. [135] Wahid et al. [136]	Abbasi and Shahid Khan [44] Alfonso et al. [15] Atzori et al. [19] Banks et al. [137] Chen et al. [138] Hussain et al. [139] LI et al. [140] Saini, Saad and Jaekel [141] Shin et al. [142] Song et al. [143] Wang et al. [144] Yang and Deng [145] Zhao et al. [25] Zhou et al. [146]	Aria, Olstam and Schwietering [126] Sucasas et al. [147]

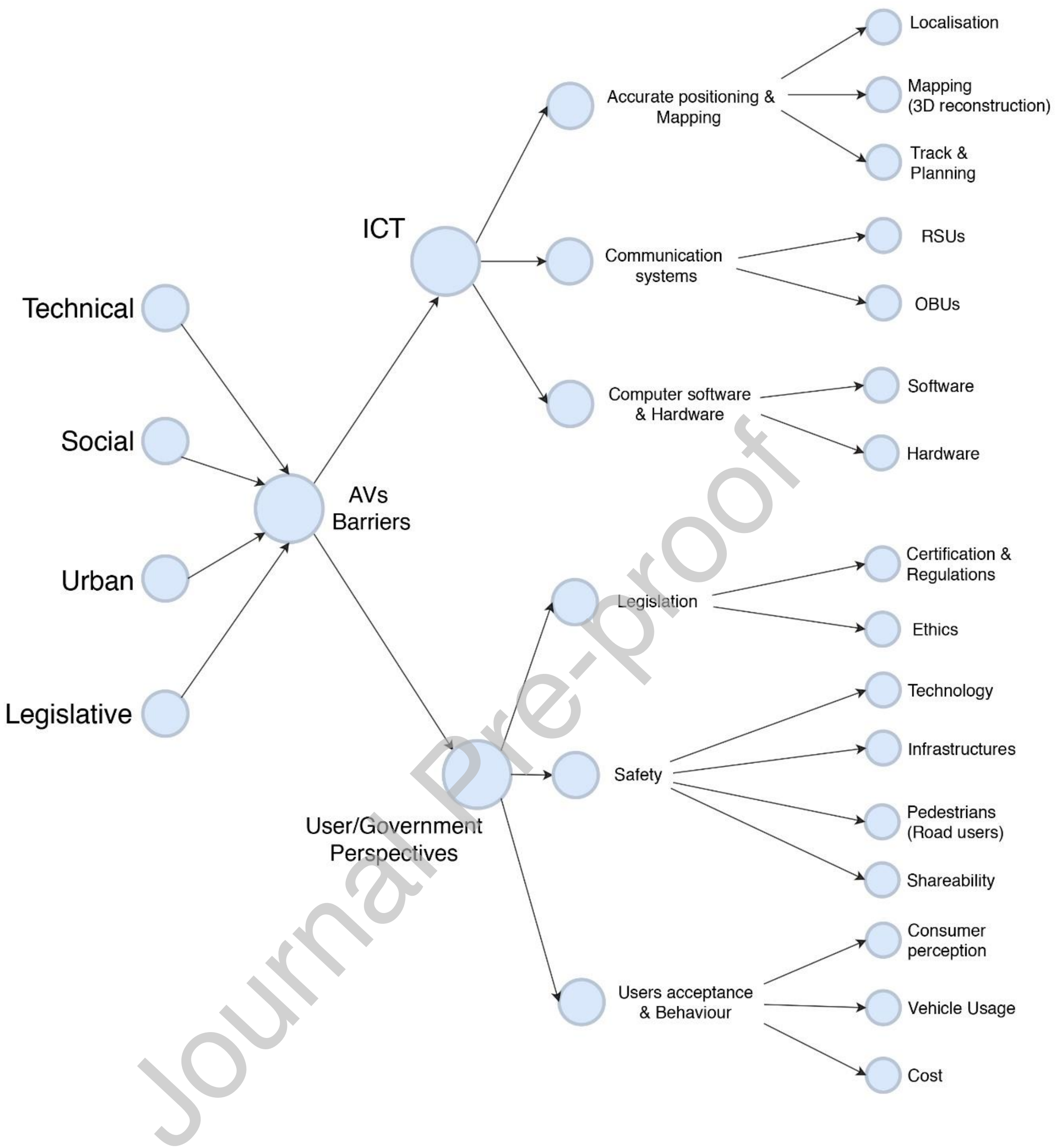

Figure 6. Hierarchy of the barriers based on the clustering method.

3.1. User/Government perspectives

This category of barriers extends on the behaviour of the end-users and how public opinions can influence the adoption of AVs based on governments actions. Thence, this category presents the following barriers: safety, users' acceptance and behaviour, and legislations.

3.1.1. Safety

Safety has been discussed extensively to be the most significant obstacle regarding the implementation of AVs. Following an extensive analysis of different articles highlighted in Table 8, we found out that tackling the safety barrier depends on addressing four domains. These domains are Pedestrians (road users), infrastructures, share-ability and Technology. Literature has addressed safety from various points. However, as mentioned above, it had been summarised into the four perspectives. All the above factors illustrated in Figure 7 that influence safety are considered obstacles that contribute to the overall barrier, which in turns must be governed by regulations. Hence, regulations are discussed separately as a barrier in section 3.1.3.

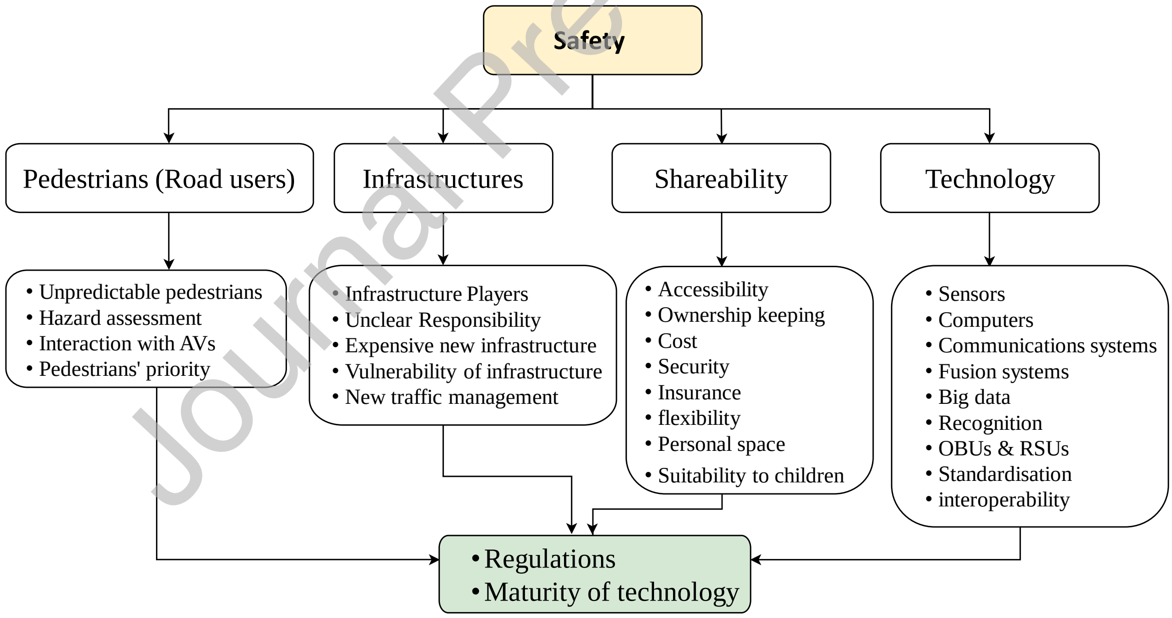

Figure 7. Various factors that are impacting Safety.

a. Pedestrians (Road users)

Statistics showed that in Britain, five fatalities and about 66 injuries occur every day [71] with 26% of road death were pedestrians [57]. As [64] stressed out, there will always be unpredictable people in the streets who cannot assess the hazard. Many experts anticipate that AVs technologies will significantly decrease pedestrians' fatalities. Urban areas will constitute a challenge as road users can be vulnerable, and they must interact with AVs in different ways [52]. Thus, the sureness of a well-designed and integrated system must prioritise the safety of pedestrians [69] and contribute to any ethical legislation. A study by [54] analysed pedestrians fatality reports in the U.S. Furthermore, they also assessed the cases that could have been avoided if an AV equipped with pedestrian sensors had been employed. The study revealed that 3,386 transportation related pedestrian fatalities could have been shunned out of 4,241, which roughly represents 80% reduction in deaths. Equipping the vehicle with such sensors can grant great benefit yet might be unreasonably costly. Section 3.2.1. expands r more information on AVs sensors.

b. Infrastructures

Introducing infrastructure players will leverage and re-balance the responsibility and will widely ensure the safety of adopting AVs. Moreover, implementing infrastructures that enable vehicles cooperation through wireless communication systems technology will improve safety and efficiency [15]. Effective vehicular communication allows high-level behaviours [63], platooning is one of these behaviours and it represents great benefits of AVs [67]. Thus, to achieve the former, various infrastructure are required. In other words, implement new traffic management strategies by traffic authorities to extend the sensing capabilities and the exchange of information. Indeed, [63] believe that complexity and challenging scenarios of our urban areas necessitate specific research in the following domains: big data, sensing technologies, IoT, Cloud computing, and artificial intelligence which in turns can develop the required infrastructure to manage them. For instance, ARTS is one of the systems suggested by [56] in the cityMobile 2 project. The system is recommended to be implemented in urban areas for efficient road and transportation. Volvo suggested Magnetic road project which requires to use magnets installed on the road surface. These 40mm×15mm magnets are fitted to guide and keep the vehicle in its lane and determine the exact position [70]. Cooperative driving achieved out of the updated infrastructure will also assist in better management and maintenance besides it will reduce the need for building new roads [73].

c. Shareability

[24] believe that Shared Autonomous vehicles (SAVs) will affect people's mobility, traffic conditions and their behaviour. However, it is not clear whether increased accessibility will reduce congestions. There is a consensus in the literature that the benefits of AVs can be maximised when they are shared. Thus, Shared mobility will alter significantly urban transportation when integrating adaptable public travel modes compared to private [61]. A study by [65] revealed that each shared AV could substitute roughly 11 private cars which has the potential to reduce car ownership that in turns will decrease traffic congestions and urban pollution. In New York, 95% of taxi trips taken in the city can be shared [72]. In the U.S. statistics have shown that 4.2 billion hours are lost in traffic congestion which equivalent to one workweek for each passenger [66].

On the other hand, shareability presents the principal obstacle to achieve the above benefits and they are related to safety concerns. The formers can be assimilated in various factors such as insurance problems, flexibility in schedules and coordination, risk of attacks and accidents [53]. Moreover, [59] stated that personal space enjoyment and the illusion of being in control are barriers to shared use of vehicles. Another essential factor discussed by [59] is the safety regulations accompanied with rear seat designated to children. Parents believe that shared or on-demand vehicle will not be suitable or sanitary appropriate; therefore, parents would still prefer to possess a private car.

d. Technology

Information and Communications Technology (ICT) permit users to alter the manner transit time and exploit it better [53]. It is believed to be the enabler of AVs application as they will offer a great deal of flexibility and adaptability of the circumstances related to traffic conditions that comply with safety and security regulations [12]. Thence, handing over control to AVs has the potential to improve safety through the vehicle to vehicle communication [8,10]. Various sensors embedded in the vehicle are expected to sense the environment for an active safety system, but the former can be limited by the road area visibility [15]. Therefore, fusing the data obtained from several sensors plays a critical role in enhancing the detection capacity that can deliver more reliable road safety, which presents a pivotal point to overcome the limitation of a single sensor [51].

Another way that ICT maximise the safety is through the knowledge of road condition that is achieved employing sensors reporting real-time data about the road conditions and the potential to be used for maintenance [51]. For instance, LiDAR scanners can detect the potholes and report it to the stakeholders for actions. Having said that, [55] argue that information about road condition such as potholes and friction are a necessity for AVs for the sake of safer and efficient travel because the information can be utilised to improve maintenance such as salting and potholes repair. As a result, ICT applications are very decisive in attaining safety either throughout the collected or provided information. A suggestion by [15] that in order the users to receive all the information related to traffic and safety conditions a hybrid communication approach is the answer by integrating both On-Board Units (OBUs) and Road-Side Units (RSUs) outcomes.

On the other hand, the European Commission (EC) consider standardisation will bring various benefits particularly data access but interoperability is an important challenge to overcome to ensure functionality [62]. Thus, [35] claim that there is a necessity to develop common technical standards to deal with interoperability and safety.

3.1.2. User's acceptance and behaviour

Adopting a new technology always has been influenced by the mindset and attitude of the people, therefore, for instance, this can affect to what extent AVs benefits are achieved [84]. Public opinion also will determine the way that vehicles manufacturers need to develop their market [94]. According to [77], many studies have demonstrated that participants are not keen to utilise driver-less technologies. A study using a survey conducted by [90] has revealed that respondents were unwilling to ride in AVs either for a short or long distance with 42.5% and 40% respectively. Unwillingness can be explained because of the users' feelings and distrust in automation [21,86]. Thus, the lack of public trust is one of the main barriers that obstruct fully adoption, this trust can be imputed in several variables such as reliability, performance expectancy and security [33]. Nevertheless, [85] assumed that people who are already engaged with technology would be more in favour of AVs and trust them.

The precise determinants of users' acceptance of AVs are still ambiguous, and there is a lack of a conceptual model that clarify the motives of recognition acceptance [93]. However, the majority of these determinants can be grouped into three categories: (i) perception, (ii) vehicle usage, and (iii) cost as presented in Figure 8. In addition to these factors, ethical issues regarding AVs have a strong influence on users' acceptance. For instance, people will prefer to ride in AVs that prioritise passenger safety above all in any situation [28].

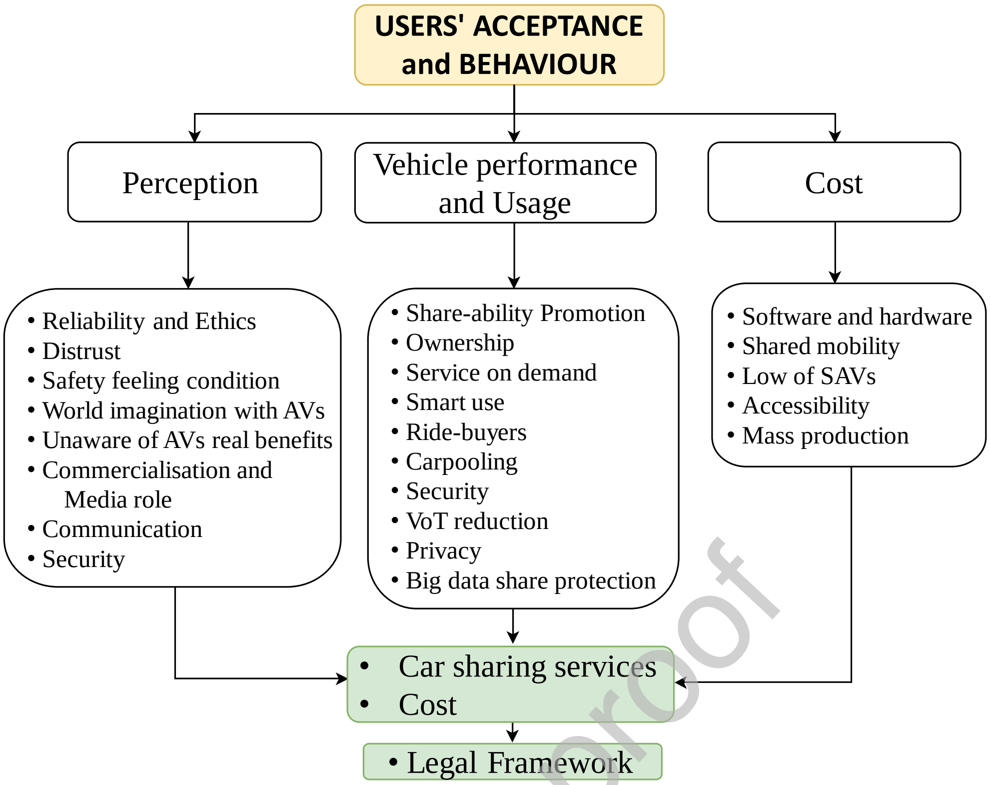

Figure 8. Various factors that are impacting users' acceptance of AVs

a. Consumer Perceptions

Many studies have been carried out in an attempt to study users' perception of AVs. [46] believe that the present comprehension of human psychobiology identified with automated driving is yet constrained and limited. Primarily, feeling a high level of safety is a vital precondition for people to accept AVs [87]. A survey by [90] forecasting Americans' long-term AVs adoption, stated that roughly 50% of the respondents were not willing to pay (WTP) to get level 3 and 4 automation. Since respondents could not imagine the world with AVs as well as they have expressed safety and reliability concerns towards these technologies. Also, people are likely to adopt AVs if they know further about their real benefits.

Who should be held responsible in case of an accident or any damaged caused by AVs? Is a conclusive question to answer. The answer to this question will have impacts on the commercialisation and the use of self-driving vehicles [79]. Moreover, increasing the sense of security on sharing services can enhance users' acceptance. For instance, including features such as "Alert button" in the apps can facilitate the users to communicate with their relatives or police in case of emergency [74]. A study by [78] employing a qualitative examination of drivers using AVs disclosed that participant do not have the same safety reservations and some of them reported that they require practice before going to the real roads.

Quality of service also affects the perception of transport mode such as the travel time reliability which is considered very influential in users travel behaviour. The former also can be used to measure the performance of such mode [53].

On the other hand, [20] argue that AVs have not been commercialised yet therein, most end-users are not familiar with these technologies. Hence, this affects the perception of AVs. Therefore, media plays a large part in forming the end-user's perception of AVs. [77] consider that consumers are less likely to use AVs if they f are portrayed in a negative perspective. In contrast, if they are advertised positively, particularly in terms of efficiency and safety consumers will be persuaded to use these technologies. Furthermore, [21] suggested that libraries can play an integral part in promoting driverless technologies; thus, librarians can provide assets on AVs such as online and printed resources. This can help raise awareness about their legislation, insurance and other different areas that have the potential to affect people lives.

In the scenario of conventional cars, drivers are blamed for their mistake in case of accidents. Whereas in the scenario of AVs the car drive itself, passengers will not be held responsible, and so this can encourage the adoption of AVs. Thus, user acceptance is positively influenced by the reliability where the responsible party in case of an accident is clear [33].

b. Vehicle usage including Shareability/Ownership and Privacy.

The definition of private and commercial transport is changing through the introduction of on-demand ride services like ride-sourcing, e.g. Uber and Lyft. However, in the scenario of AVs, critical questions must be addressed like how the market will be organised and will they be owned personally or run by private companies or integrated into public transport? [76]. Nevertheless, in all cases, matters like congestions and regulations must be dealt with. [88] argue that issues like congestion and pollution will not vanish with AVs but smart use of it can lead to sustainable mobility. [10] believe that AVs taxis will become legal and viable and serve as same as personal cars; this will minimise ownership demands. As a result, if AVs in shared mobility has proven its effectiveness, this will influence users' usage of them. People either in the suburbs or urban areas will respond to AVs in a variety of ways, [82] stated that private AVs would reach its high peak before shifting to various type of shared transport-on-demand. Having said that, it is significant to concentrate on how to move users to ride-buyers to reduce ownership rather than focusing on promoting AVs [59].

Carpooling is one of the transportation modes that policymakers should encourage and shall be integrated in the public transportation mainly if the fares were considered, which can contribute to the long-term sustainable transport [81]. Despite the above recommendations were based on a non-autonomous vehicle, this also could be a form of shareability that would be used in the case of AVs.

[80] believe that the widespread of car-sharing services is changing the perception of citizens as they are moving from car ownership to a service on demand. AVs will reform the whole sharing services concept not only opportunities to share a car but also seats and cargo spaces [34]. As a result, this will be implied as well in the case of AVs.

Combining the reduction of the value of time (VoT) and providing new mobility services has the potential to affect mode choice and passenger's behaviour [83]. Subsequently, aspects of ownership and shareability of AVs will have impacts on the acceptance of users.

Privacy will constitute a vital impediment that will manipulate users' approval of AVs. Indeed, information gathered by AVs through V2X communication can be misused and lead to fatal consequences and this present a grave concern for users [13]. [15] indicate that the willingness of end-users to share their data coming from the vehicle will depend on data protection principles that impose compliance with a legal framework to implement a cooperative intelligent transport system (C-ITS). In addition, to prevent privacy, violation data protection protocols must be embedded at the design stage of AVS.

c. Cost

Cost can slow down the adoption of AVs due to their long lifespan [84] because integrating sensors technologies will be unrealistically costly [54]. In fact, a study by [89] expected that the total per-vehicle software and hardware will start roughly at £3,000 by 2025 and will decrease to the half by 2035.

[92] outline that with the social acceptance of AVs and the reliability of SAVs will decrease the cost of usage. Hence, social acceptance of driverless cars is very crucial in determining their price. In addition, low-cost of SAVs will increase shared mobility if they are reliable and accessible as stressed by [75] that the key of car sharing will rely distinctly on on-demand access. The survey conducted by [92] assessing public opinions about AVs in Austin has demonstrated that more than 80% of respondents were reluctant to pay more for SAVs that the existent carsharing companies are charging. Although the cost currently presents an obstacle for users to full adoption of AVs, the former will be a temporary issue as it will change with the mass production.

A study by [14] using total cost of ownership (TCO) has compared AVs, and conventional vehicles (CVs) including private cars, taxis, and trucks concerning cost suggested that commercial applications will be the highest beneficiaries from fully automated driving. The potential to adopt them in the logistics depends on materials handling like loading and unloading.

To conclude, all the above factors are very substantial in determining end-user's acceptance of driverless technologies. Since IoTs will converge the physical world with computer hardware and software, it is not possible to ignore the users' experience [91]. However, the actual performance of AVs and how well they behave in reality in our roads will eventually decide social acceptance [35].

3.1.3. Legislation Including Certification, Regulation and Ethics

AVs technologies are rapidly turning into reality, despite they are still not mature enough [30]. This implies that the legislation of the matter is challenging and need to be addressed shortly. In addition, ethical reasoning has attracted significant interest in machine ethics [95] as it is crucial to learn the convenient way to embed it into AVs. Also, a study by [32] indicated that the national policies would influence AVs adoption. Figure 9 represents the factors found in the analysis that influence the legislation to implement AVs and CAVs.

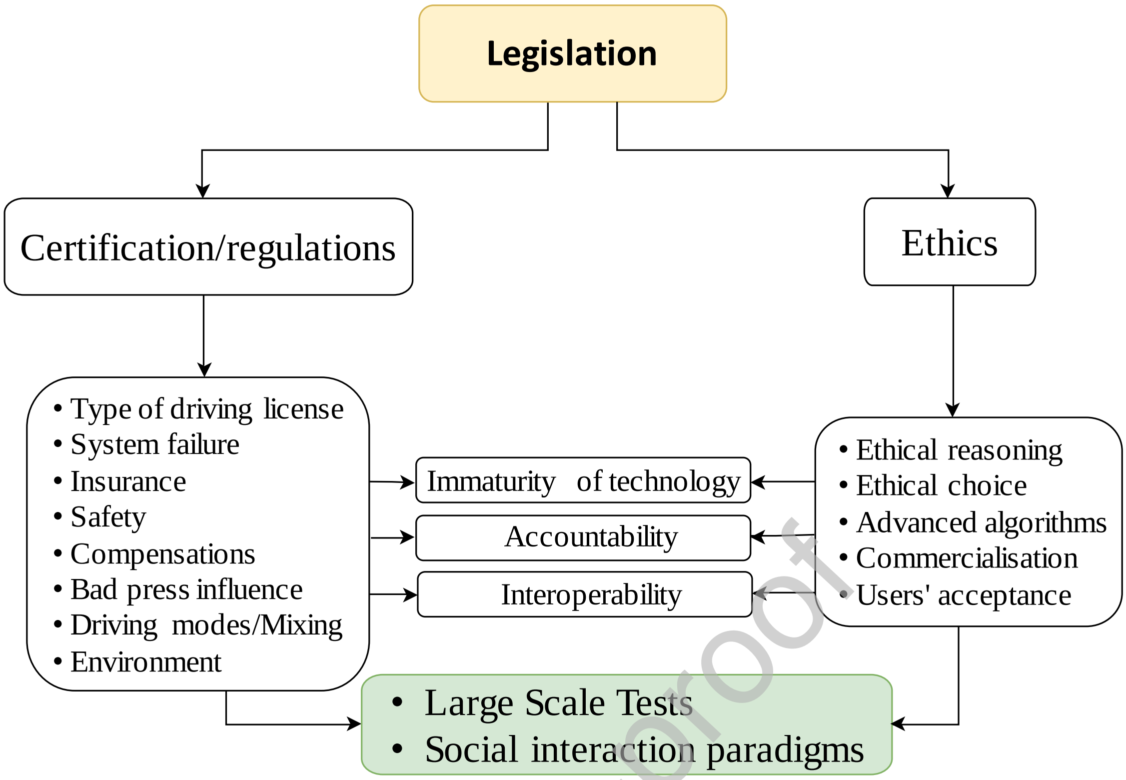

Figure 9. Various factors that are impacting AVs' Legislations.

Currently, many questions are accompanying AVs, noticeably, who is accountable in case of an accident? as well as to whom or what passenger be given instead of driving licence? [30]. Legal issues are a prime worry for the application of AVS since responsibilities must be evident in the case of a system failure [98]. Liability is a paramount factor as it has a strong liaison with insurance, as stated by [105] such a law will be decisive to answer the question of whom cost accidents borne by, is it the victim, another actor or shared (Co-responsibility). Thence, governments need to work with manufacturers and research organisations to embrace this new mobility and address the arising legislations issues to ensure safety as much as possible [99,100]. Furthermore, policies regarding AVs should be developed neutrally and away from the “bad press” influence [77].

Ethical considerations are very crucial in determining AVs decision-making, which likewise would reflect the relevant regulations can be framed. Not all the crashes can be avoided; thus, AVs have a tough and complicated ethical choice to make. For instance, in case of decision making should AVs be running over pedestrians or save them at the cost of its passengers? [104]. In fact, these scenarios will affect the commercialisation of AVs and users' willingness to adopt them.

To develop a legal framework that at least ensure the safety, encouraging AVs large scale tests are indispensable for their deployment in our roads. Besides, these tests can lead to advance the technological aspects and the applicable legislation [79]. For instance, in September 2017, the USA house of representative has passed the SELF DRIVE Act to support AVs testing. As mentioned in the ACT, several new regulatory tools are being addressed, such as *"require manufacturers to publicize their cybersecurity and data privacy plans"* [96].

Research by [102] studied the possibility of using three different lanes policies for a diverse combination of driving modes. The first scenario which is a complete separation between both modes, where the 1st lane is dedicated only to AVs and allows platooning and 2nd for CVs only. The second scenario, 1st lane, is dedicated for mixed traffic both AVs platooning and CVs, whereas the 2nd lane is designated only for CVs. The final scenario, which is the opposite of the second scenario, Where the 1st lane is devoted exclusively for AVs whilst the 2nd lane is for mixed modes. The study concluded that the first scenario is the most likely one to be successful as it permits a smooth AVs transition. These scenarios can extend further the legal framework by either limiting the lanes for different driving modes or an opportunity to develop regulations while observing their behaviour in testing phases. Another study by [103] supports dedicated zones for AVs as an option for future policies in case of mixed driving modes or their phase of penetration. Despite the limitations of their study model, the results demonstrated that it would help to decrease the travel time.

Many of the previous scholars highlighted several areas that require necessary legislations. Nevertheless, the most important policies are safety, environmental, interoperability, liability, infrastructure and cost [97]. On the other hand, [35] stated that the outcome of the previous exploration regarding AVs policy direction is a very difficult challenge to guarantee public safety with rapid technological advances. In addition, [35] suggested several questions that they believe the answer to them will help guide the future policy for AVs. Policies should not be developed only towards the technological perspective but also social interaction paradigms such as between users and AVs and road users. Policies are expected to accelerate the development of AVs [97]. In the light of developing a legislative tool for handling civils and AVs liability, a commission by the European Parliament urged to consider three elements; *"limitation to liability",* system of liability determination (is it strict liability or risk management approach), and *"Obligatory insurance scheme and guarantee fund"* [101].

3.2. ICT

Unlike the first category, this set of obstacles includes all that is related to technology. Hence, the next section expands on the following barriers: Computer software and hardware, Communication Systems V2X/VANETs, and Accurate positioning and mapping.

3.2.1. Computers' software and hardware/Sensors

[121] stated that the idea of AVs had been around for a century, and the innovative advance in sensing technologies and computer made it possible. In recent years, computers are becoming necessary parts of vehicles taking care of several tasks automatically like cruise control [30]. Not only cars have to sense all the surrounding areas but also must understand what they are sensing. Hence, for the AVs to perform as desired, a significant development in algorithms is compulsory [30] so they can act and decide what to do in a split of a second [69]. Therefore, two fundamental elements are essential, which implies developing software and hardware/sensors, as illustrated in Figure 10.

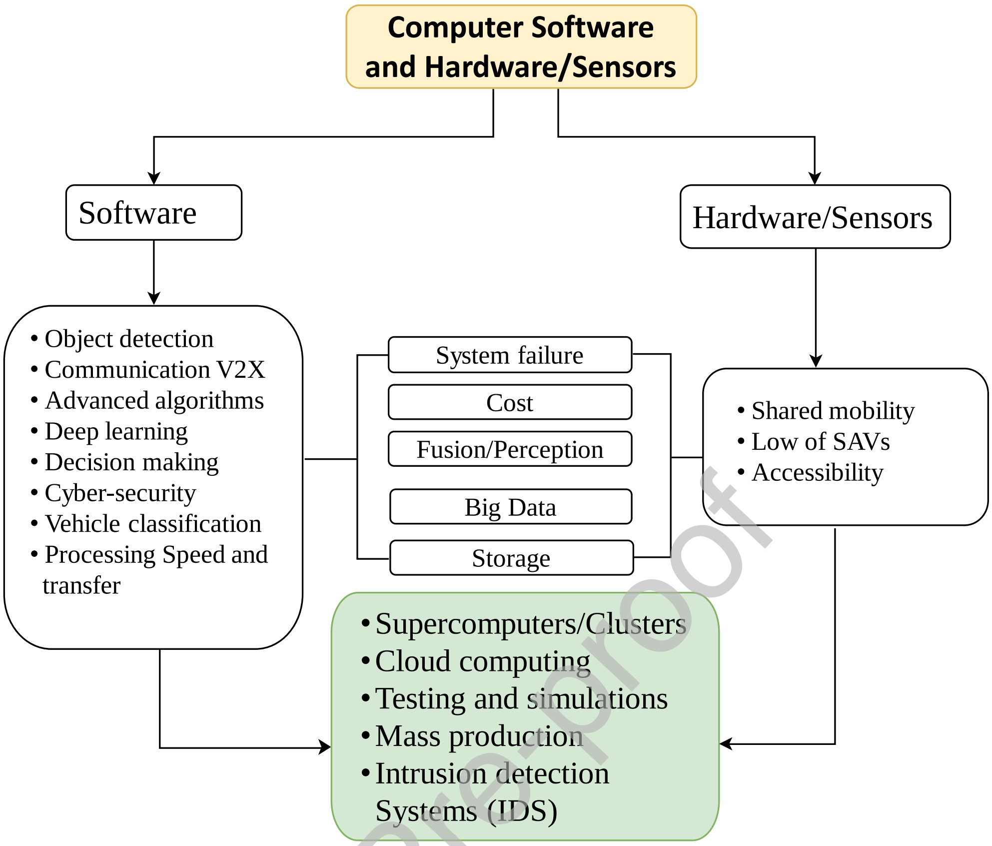

Figure 10. Various factors that are impacting Computers' Software and hardware/sensors.

According to [99], the complication of AVs is that there are no fundamental or sophisticated algorithms that can cover all the possible accidents which indicate that there is still a lot to know about automated technologies. Very advanced computer software and hardware needed for the collected information coming from various sensors, LiDARs and cameras for the fusion process that assist AV decision making. At full adoption of AVs, it is highly expected to eliminate the human errors accidents though Computer software and hardware related hazards could augment [14]. However, [117] believe that intrusion detection systems (IDSs) can aid to defend against cybersecurity risks. Hence, this kind of approaches needs to be designed in the AVs and networks, which also presents a challenge.

According to [124], AVs software systems can be comprehensively grouped into three classifications perception, planning and control. AVs will always depend on fusion data to assure reliability [51]. Figure 11 depicts AVs system architecture, and the processing phase is where most of the computers software are needed, which what is also called a computer vision.

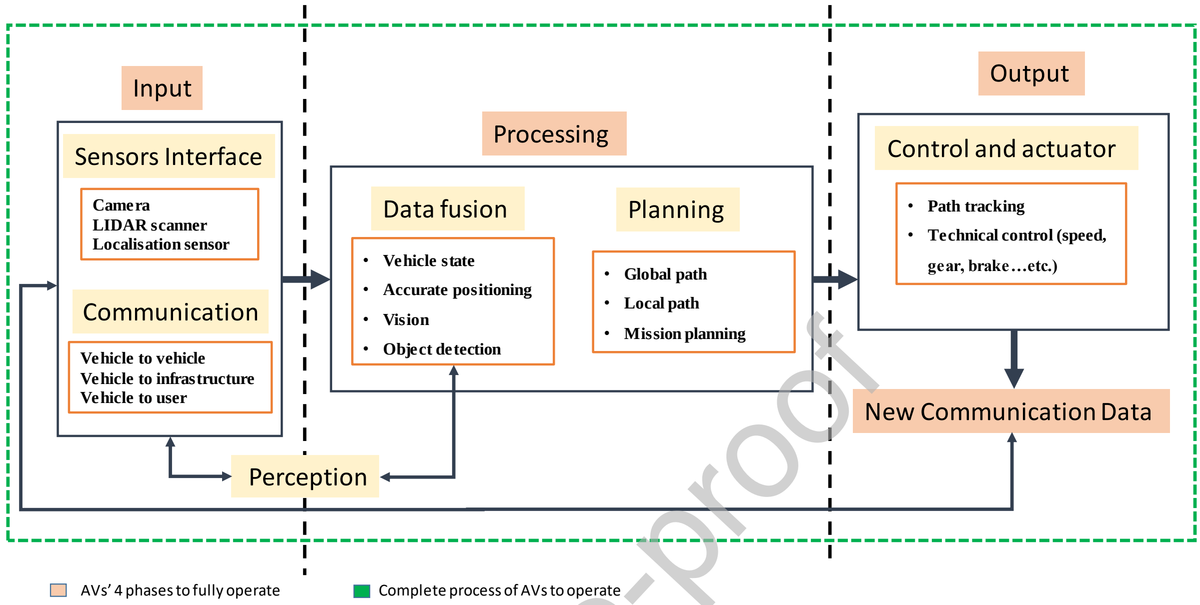

Figure 11. Connected autonomous vehicle system architecture overview, reproduced from [113,124,128].

All software and hardware are human-made and conceivable to a failure and can lead to catastrophise on roads [124]. Therefore, AVs require new system architecture and impose to have a centralised supercomputer to manage data generated from all the sensors ([126]. In addition, [125] argue that vehicle classification is significant for overall (ITS) efficiency. Although software-based classification has a significant time constraint, they are more robust than hardware-based classification. As a result, the former demands robust computers.

AVs are expected to deal with diverse data containing road conditions, obstacles, communications and many others. This enormous data is collected and processed every second and the transferring data amongst AVs will be with speed up to 1GB per second [129], which requires powerful computers and big data storage hardware. According to [119], processing big data is beyond the usually utilised PCs; hence, it entails for a super-

PCs or clusters. Over 250 million of lines of code need to be programmed to build AVs software which can vary from AVs' category to other [122].

Both software and hardware need extensive system testing before supplementing to the real world [123,127] which requires a considerable amount of time for the process of testing and legal approval. [121] argue that selecting suitable testing scenarios that reflect the real world is significant. For instance, AVs testing started in 2009 by google, and over 2 million miles have been carried on actual streets [118] and still ongoing to develop how AVs can be deployed.

On the other hand, simulation tools can play a critical role in the integration of AVs/CAVs. They can assist operations managers in assessing their performance and capture the facilities needed (infrastructure) [29]. Thus, highly customised simulation tools are a necessity.

3.2.2. Communication Systems V2X/VANETs

With the advent of IoT, AVs are at the centre of ITS, and they are already equipped with several innovative technologies that permit them to establish communications and cooperation with different units including vehicles (OBUs) and RSUs through short-range wireless networks [19]. In addition, Figure 12 represents various factors that affect AVs' communication.

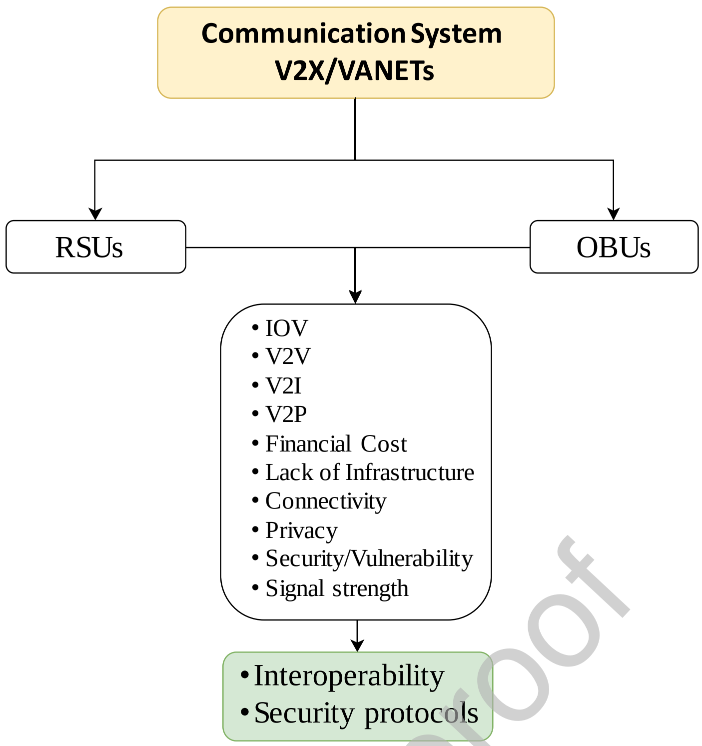

Figure 12. Various factors that are impacting AVS' Vehicular communication.

The increasing interest in vehicular communication has led to the emergence of Internet of Vehicles (IoV). IoV is becoming the critical empowering technology to implement future AVs that can be achieved through Vehicular Ad-hoc Networks (VANETs). The former is an offshoot of mobile ad-hoc networks (MANETs) and have ended up being the essential building for ITS [15,44,138,139]. These VANETs are used to provide communication between vehicle and different nodes V2X: these communications can be classified as follow: Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and Vehicle to Pedestrians (Users) (V2P) [25,126,134,137]

Vehicular communication will result in a better ITS application. Nevertheless, [130] believe that the primary hindrance of its implementation is the financial cost because currently just a small part of overall road infrastructure that can be ready for V2X thus significant economic sources are needed. A further concern of employing VANETs is the comprise of privacy and security because VANETs expose critical information of the vehicles [141]. A large number of scholars have discussed this arising issue and proposed various solutions [131–133,136,143,144,147]. For instance, [145] suggested a privacy protection mechanism that permits vehicles to utilise pseudonyms when data exchange periodically in order to obviate the consistency of attackers' tracking. In addition, data transmission within the network presents a challenging task caused by high mobility and continual location changes [135,142,146]. Since the urban driving environment is complex, building a reliable VANETs also depends on sufficient signals strength amongst its receiver and connectivity [140].

3.2.3. Accurate positioning and mapping

According to [108], due to the recent competition on the self-driving cars, a large number of methods and algorithms have been developed regarding the machine learning, image processing, localisation, decision making and communication. [109] believe that autonomous navigation is the crucial technology key for driverless vehicles, as it provides accurate positioning to a few centimetres. Figure 13 Illustrates the key factors affecting AVs navigation.

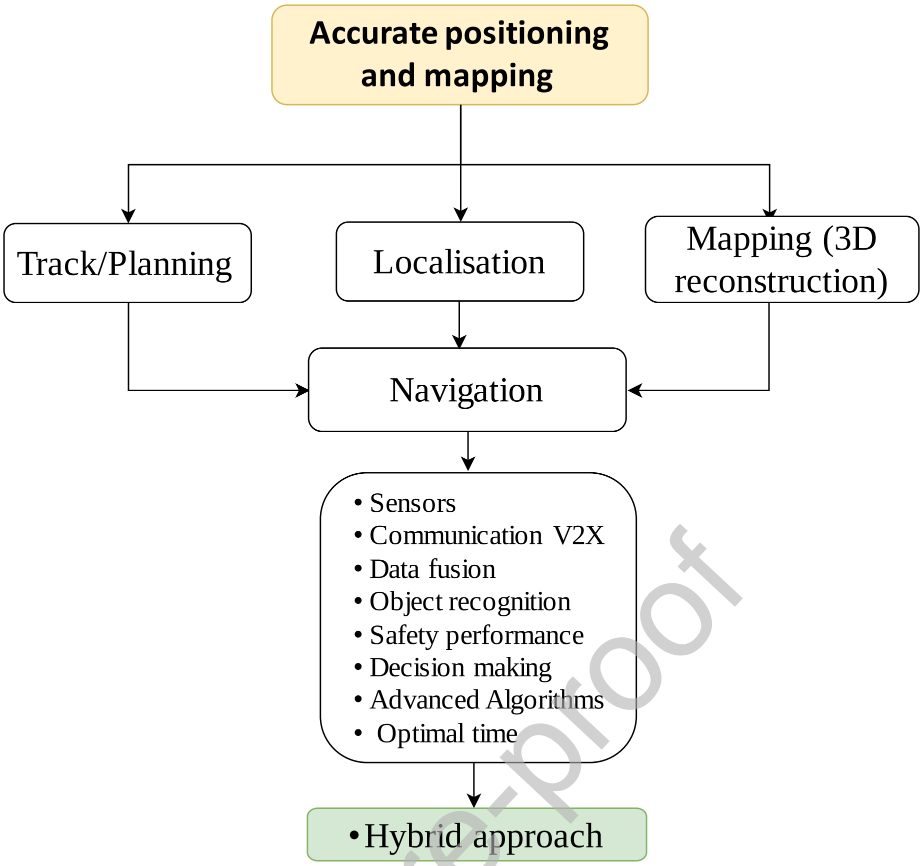

Figure 13. Various factors that are impacting Accurate positioning and mapping (Navigation).

Autonomous navigation is about having the ability to perceive, track, map, real-time moving planning and localise [116]. There is a necessity of precise localisation exceeding the available inertial guidance systems GPS that would enable AVs navigation to function correctly in urban environments. Using GPS and IMU with LIDAR can generate high-resolution ground maps (3D reconstruction map) which will be utilised for delicate localisation [115]. Thus, for AVs to perform highly, real-time navigation and accurate positioning are enabler keys; actually, Global Navigation Satellite Systems (GNSS) is one of the preferred options for delicate positioning [107].

A multimodal fusion data suggested for precise positioning using autoregressive and moving average (ARMA) models that based on GPS-IMU and DR navigation data. Despite using this model that achieve precise localisation, it generates and accumulates errors resulted from DR [109]. Thus, more research needs to be done on AVs navigation.

Not only AVs are required to move from point A to B in real-time but also with high safety performance, accuracy in positioning, precise objects recognition, prerequisite decision and traffic law submission [108]. Therefore, path planning algorithms are being adapted to address the complexity of urban traffic scenarios because these algorithms are run in parallel with data fusion of different 3D scanners, navigation systems and cameras.

Path planning is very critical for AVs navigation [106,110–112,114]. Path planning algorithms are constituted of mission planner, optimal path and longitudinal motion planner. These algorithms are responsible for vehicle mode decision, reaching the destination without collision and acceleration and deceleration [113]. Some methods are being used; Voronoi Diagrams, Fuzzy logic, VFH (Vector Field Histogram) and graph search to name a few. Moreover, Detailed and more processes are explained in [110].

Nevertheless, [108] suggested that the best option is to use a hybrid path planning system and is achieved by local and global preparation. The former is to create an optimal path avoiding obstacles, whereas the latter is to maintain the vehicle by smoothing the trajectory [111].

Section 3 of this paper has analysed the state of the art of literature and presented the current and expected obstacles of AVs. Moreover, each of the suggested barriers has been separately discussed in detail. Nevertheless, to understand more precisely the importance of knowing these obstacles, we have integrated them with the AVs system architecture (see section 4). This integration will permit us to understand how these barriers affecting the performance of AVs; thus, solutions and actions can be taken to be prepared and ready to adopt AVs.

4. Conclusions

This paper presented a comprehensive systematic review of AVs barriers to full adoption. At the outset, we started looking at recently published papers dealt with the various problems facing AVs. Then, we believed it was necessary to list the prospected benefits and risks of AVs. This is to stress further on the importance of overcoming their current and potential obstacles to achieve their interests and manage their risks. Thus, the findings presented in section 3 are integrated with AVs system architecture. Figure 14 shows the integration of all six barriers and AVs system architecture to full operation as well as it illustrates where the barriers are affecting the whole AVs' system (shown with coloured arrows). Overall, the analysis concludes that all obstacles are intertwined and cannot be separated. For example, in the input phase, the fourth obstacle is the biggest obstacle that affects this stage. However, since the overall obstacles are twisted, this does not mean that the other obstacles do not impact. In the same context, the fifth barrier also affects clearly at the input phase but also influence the output phase significantly. On the other hand, Obstacle 1, 2 & 3 do not particularly affect each stage but generally affects the overall system.

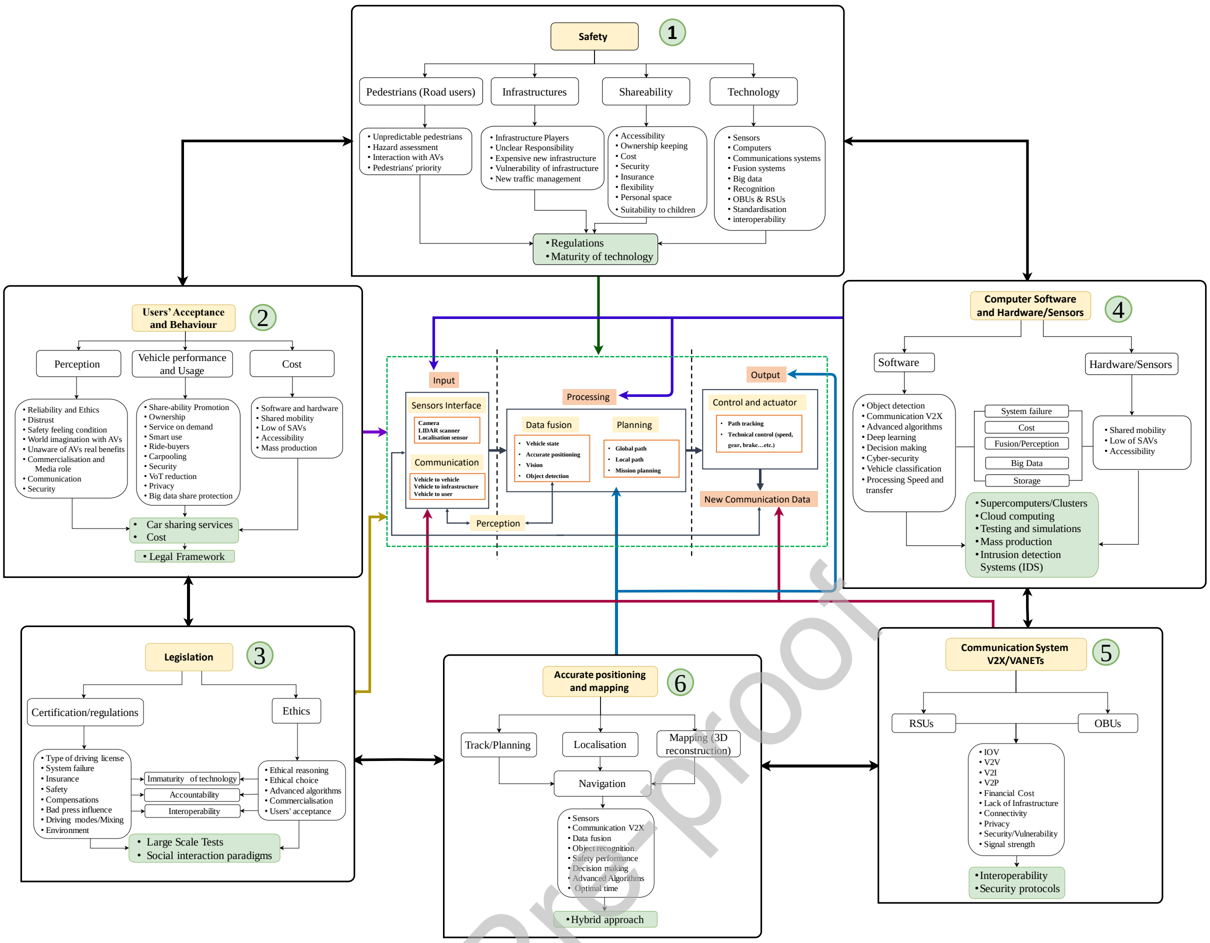

Figure 14. Framework assembling all the barriers and their factors combined with AVs system architecture.

The reason for identifying the AVs' obstacles is that their analysis will lead to the knowledge of the internal and external factors contributing to their composition; thus, knowing these factors will lead to finding suitable solutions, whether the latter is technical, social, legislative and/or urban. For instance, analysing the barrier of users' acceptance and behaviour, we can understand that the unwillingness of people to use AVs is due to their distrust feelings towards automation. The former is explained that people still do not trust computers to drive them, although they are believed to be much safer than human driving. As a result, this distrust can be linked to a lack of public test, media role, cost, shareability and many other factors. Consequently, a good understanding of these factors and their overlap enables us to know how to address them and thus achieve full adoption of AVs.

The study suggests a summary of the actions and recommendations needed to be taken to promote the adoption of AVs. Table 9 shows these actions that should be made based on the analysis of the barriers.

Table 9. Study recommendations to adopt AVs

<table>
<tr><th colspan="2">Barriers</th><th>Actions and recommendations</th></tr>
<tr><td rowspan="3">User/Government perspectives</td><td>Users' acceptance and behaviour</td><td rowspan="6">Maturity of technology including: Supercomputers/cluster, cloud computing ad Intrusion detection systems (IDS)
Simulations to study their impacts on different aspects such as energy and traffic
Regulations/ Legal framework that protect users
Car sharing services and cost considerations
Enable Large scale tests of AVs in cities
Analysis of various Social interaction paradigms
Use of Hybrid communication system approach
Develop Interoperability standards
Develop and embed Security protocols
Mass production</td></tr>
<tr><td>Safety</td></tr>
<tr><td>Legislation</td></tr>
<tr><td rowspan="3">Information and Communication Technologies (ICT)</td><td>Computer software and hardware</td></tr>
<tr><td>Communication systems</td></tr>
<tr><td>Accurate positioning and mapping</td></tr>
</table>

The next step is to study in-depth their interrelatedness and develop questionnaires designated both to end-users and experts to validate the framework content (Figure 14). Another matter that must be considered is that there will be other barriers evolving, such as when extensive large tests are being conducted and policies are employed in the real world. There is a need to combine the framework suggested and the potential evolved barriers.

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CRediT author statement

- **Nacer Eddine Bezai:** Conceptualization, Methodology, Software, Formal analysis, Investigation, resources, Writing - Original Draft, Writing - Review & Editing Visualization.

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- **Moulay Chalal:** Methodology, resources.

- **Fodil Fadli:** Writing - Review & Editing, Supervision.

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