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Review

Smart Mobility and Its Implications for Road Infrastructure Provision: A Systematic Literature Review

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Abstract: Emerging smart mobility concepts suggest solutions for more effective and environmentally friendly transportation. Given their importance in enabling smart mobility, road infrastructure networks have received limited attention. Questions concerning the development of various isolated smart mobility solutions dominate the discourse, including only a few detached and unaligned implications towards road infrastructure provision. As a result, the development, operation, and functionality of road infrastructure networks are remarkably unchanged, and the deployment of smart mobility solutions remains tentative. The objective of this study was to investigate how road infrastructure must adapt to facilitate a smart mobility transition, not for a single solution but as a socio-technical system transition. As no compiled knowledge for this objective exists, a systematic literature review was performed to consolidate and inductively analyse the literature on smart mobility solutions. Based on the results, implications for road infrastructure provision were identified, and as a path forward, a conceptual model for the digital transformation of road infrastructure is presented. By using smart mobility as the antecedent for changes in road infrastructure provision, this paper contributes to an increased understanding of user-driven, industrial transformations and advances the current product/project view on digitalisation in infrastructure provision with broader value implications. The main contributions of this study are concrete pathways for road infrastructure provision that support smart mobility.

Keywords: smart mobility; road infrastructure; digital technology; digital transformation; systematic literature review

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1. Introduction

In recent years, policymakers, practitioners, and scholars have postulated the demand for a smart mobility transition. While the existing transport system brings many benefits to the users, it also has an enormous environmental, financial, and social impact. These include Co2 emissions, pollution, the loss of biodiversity, accidents, congestion, the allocation of limited financial resources, and car dependency. Smart mobility describes a new way to operate and organise transport systems, which is supposed to be cleaner, safer, and more efficient [1]. The concept of smart mobility includes a wide range of technologies and solutions that are already emerging or are the subject of R&D efforts. The key principles of smart mobility are flexibility, integration, and social accessibility, whereas the most prominent solutions are (semi-)autonomous vehicles and the shift from car ownership towards an interoperable package of on-demand mobility services [1]. Smart mobility uses advanced information and communication technology as well as digital technologies in combination with physical infrastructure [2]. Adapting the road infrastructure is pointed out as a priority for the smart mobility transition [3], and a discussion on how to synergise road infrastructure with the demands of connected vehicles is ongoing [4–7]. Road infrastructure is a labour- and capital-intensive, (quasi-)public, and highly localised sector characterised by large physical assets, long planning periods, and lifecycles of up to 100 years after investment. These sectors are hard to change [8]. As a complicating factor, the construction industry delivering road infrastructure, having a reputation for being conservative and fragmented, struggles to adopt new technologies at scale and benefit from digital transformation [9–11]. So far, little is known about the consolidated demands and expectations of the variety of smart mobility solutions towards road infrastructure provision and the ability of the sector to embrace them.

The smart mobility transition will translate into changes in road infrastructure functionality and how it is provided [12]. Neglecting these changes may hamper desired transformations in transportation and omits the possibility of overcoming digitalisation and sustainability shortcomings in the road infrastructure sector. The objective of this study is to investigate how road infrastructure must adapt to facilitate a smart mobility transition, not for a single solution but as a socio-technical system. This study aims to investigate the implications of smart mobility for road infrastructure provision by better understanding the commonalities of smart mobility solutions and their possibilities but also shortcomings. The method of a systematic literature review is chosen with a threefold purpose: (1) to provide insights into the smart mobility transition; (2) to discuss how, if, and why these insights are useful for road infrastructure provision; and (3) to develop a conceptual model on the relationship of smart mobility transition and road infrastructure provision.

During the systematic literature review process, a sample of 56 smart mobility frameworks, concepts, and solutions was carefully selected and analysed in depth. Digital technologies were pointed out as the underlying enabler for smart mobility and used as the main selection criteria. As a result, pathways and related benefits for road infrastructure provision were synthesised and critically discussed. As a path forward, the concept of socio-technical transitions, a useful and common starting point for exploring the smart mobility transition [1], was applied to develop a model for adapting the value creation path in road infrastructure towards smart mobility demands. In doing so, this study follows a broad research agenda on how to make road transport more sustainable and efficient [13–16]. Linking two until-now widely separated research streams, road transportation and infrastructure provision, practitioners and policymakers can use this study as a source of knowledge to realise their efforts in putting road transport and construction on track for the future. The construction sector is guided to persist meaningfully by creating infrastructure that supports changing transport demands and expectations and, by this, building competitive advantages at organisational and industrial levels [11,17,18]. The study further contributes to management research with a practical application of a user-driven, industrial transformation through changes in value creation paths [19–21].

The paper is structured as follows: first, a conceptual foundation including smart mobility, digital technologies/digital transformation, and digitalisation in road infrastructure is presented; this is followed by an outline of the research method before the results are presented; finally, the implications are discussed and a model for the digital transformation of road infrastructure is suggested.

2. Conceptual Foundation

2.1. Smart Mobility

Transport is a fundamental societal function [22] and a prerequisite for welfare services and national competitiveness and growth. Historically, the mass adoption of self-owned, fossil-fuel-powered motor vehicles and their use-value has depended on expansive physical road infrastructure systems [1,23]. Road transportation is undergoing a continuous transformation [24,25], and in line with the global trends in digitalisation, road transportation is supposed to change dramatically due to the widespread use of digital technologies [1,26].

As a direct response to increasing traffic accidents, congestion, and the environmental and social challenges associated with road transportation, frameworks for deploying intelligent transport systems (ITSs) in road transport were released over a decade ago [27]. ITSs integrate telecommunications, electronics, and information technologies with transport engineering to plan, operate, maintain, and manage transport systems. Despite the wide availability of ITS solutions, their implementation is lacking, as traffic accidents and congestion persist, and the environmental impact of the road transport sector remains considerable, including a substantial contribution to CO_2 emissions [28,29]. Overall, the sector appears to be resistant to a broader ITS deployment, possibly because ITSs represent purely technical solutions with limited attention to organisational implications and real-life practices in the sector [27,30,31].

The most dominant image of smart mobility describes the combination of a smart transition, which denotes the transition from active human intervention using dumb technologies towards human interaction with intelligent and connected technologies [32], and a mobility transformation, which denotes the transition from car dependency to personalised services on demand [1]. Smart mobility incorporates a wide range of modes of transportation, i.e., scooters, bicycles, buses, trains, subways, cars, taxis, (semi-)autonomous vehicles, and walking. Smart mobility articulates a new paradigm for road transportation and is supposed to describe not only technical innovations but introduce a wider socio-technical and economic transition [1]. The dominant optimistic practitioner rhetoric proclaims smart mobility as a holistic and revolutionary way that society's transport demands can be satisfied [33]. Even though publications have increased massively during the last ten years and some key elements and principals can be defined, there is little consolidated knowledge on the broader implications beyond a single concept/solution, and it appears diffuse how road infrastructure, pointed out as a critical enabler for smart mobility, has to adapt to a variety of solutions and concepts, not only technical but also organisational. The academic literature has not yet sufficiently answered this question. Related works may see smart mobility as more than one solution [1], but their focus is on the governance of the whole system, not on the infrastructure implications. Others describe infrastructure implications but only those that are "technical" and from the perspective of a single function [5,7].

2.2. Digital Technologies and Digital Transformation

Significant developments in information, communication, and connectivity technologies have unleashed the potential for new and disruptive digital technologies [34]. The literature primarily uses the term "digital technologies" to refer to technologies such as the internet of things (IoT), big data, platforms, and blockchain [34–37]. Smart mobility concepts and solutions extensively depend on digital technologies [2]. To encompass the profound changes brought by digital technologies, digital transformation (DT) has emerged as an essential phenomenon in the information system and management literature [37–40]. DT describes changes at the system and organisational level due to the reconstruction of organisations, economies, institutions, and societies as a result of two developments: the conversion of physical products into a data format and the digitalisation of business models and processes [41]. However, this transformation does not affect all organisations and sectors equally. Some organisations face challenges in handling the opportunities and risks of DT [38,39]; for others, new digital technologies present an existential threat [36]. Sectors with a linear series of activities and well-established incumbents, such as road infrastructure construction, are likely to be challenged by young digital companies that bear no resemblance to existing structures and processes [8]. Product-oriented sectors are facing a pressing need to incorporate services and digital products as part of their core offerings [42]. This makes digital transformation an adequate concept for developing a framework for road infrastructure transformation.

2.3. Digitalisation in Road Infrastructure Provision

In the management and information system literature, the distinction between digitalisation and the emerging phenomenon of digital transformation appears to be related to the introduction of digital technologies [37,38,43–45]. The construction management literature adopts a limited view of digitalisation and digital technology implementation, focusing on potentially improved efficiency in production processes and project delivery inside the construction industry supply chain [20]. Recent publications have started a discourse on the value implication of digitalisation in construction and changes in user demands, behaviour, and expectations due to the use of digital technologies, both inside the industry and on the demand/user side [19–21]. The research agenda for digitalisation in construction ignores problems with real-life practices and does not articulate the possibilities of using digital technology to accommodate better exchanges with the user/consumer or to develop new value-creation paths [20].

Generally, the digitalisation concepts and frameworks used for road infrastructure were developed in other sectors or for a broader scope [46,47]. Digital transformation has slightly emerged in road infrastructure research related to increasingly adopting digital technologies in BIM (building information modelling) applications [48,49].

For [23], road transportation is trapped in a self-reinforcing cycle of induced demand that generates more physical road construction, i.e., traffic growth and congestion provoke the provision of more road infrastructure. The increasing concern about global warming [50] has renewed attention towards road transportation and the road infrastructure construction sector's responsibilities, shortcomings, and desired transformations. Advanced knowledge about the social and technical system of smart mobility and the demands and implications towards road infrastructure development is crucial in this situation.

3. Method and Data

This paper adopts an inductive approach to review the knowledge of smart mobility concepts. As adapted from grounded theory methodology [51], the rigorous process of defining a systematic literature review (SLR) aids in setting the scope of the review, searching, selecting, coding, and analysing the literature sample and presenting findings [52]. The SLR ensures transparency and replicability in the iterative process of using existing smart mobility knowledge to understand the changing demand side and its influence/opportunities for road infrastructure provision.

As a first step, boundaries were drawn to determine the scope of the review. This includes the choice of sources (databases and search terms) and multiple inclusion and exclusion criteria. To understand what the existing knowledge on smart mobility covers and offers, several queries were run against different online databases. To remain consistent, the most relevant digital technologies [34,36,37] were added as keywords to the search term (see Figure 1). The initial search indicated that the topic is of high interest in both research and practitioner-oriented outlets. Smart mobility is also used to acquire the audience's attention, utilising it as a buzzword. To focus the effort on selecting all potentially significant literature while ensuring quality research, Web of Science and Scopus were chosen as relevant databases, and the following inclusion criteria were defined: (1) peer-reviewed articles/reviews, (2) available in the English language and (3) the search terms need to appear in the topic, abstract, or keywords. Refining through an in-depth review and full-text analysis, the sample was further narrowed down, filtering out literature in which the search terms were used in the wrong way (e.g., "political platform" instead of "digital platform"), used as one of many different applications (e.g., that the solution is primarily developed for "smart health"), and purely technical literature (for example, ICT hardware components). See Figure 1 on the SLR adoption and the SLR process.

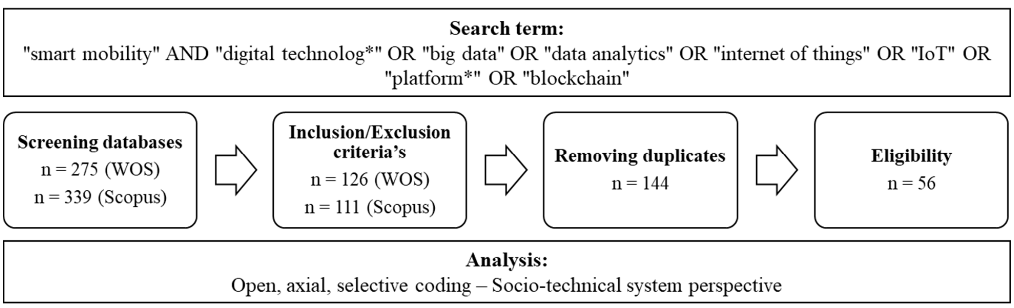

Figure 1. Adoption of the SLR method (* = ending of word is not defined).

The analysis was divided into two parts—descriptive and thematic analyses [53]. Descriptive information was gathered by collecting several data points for each part of the literature sample. A word frequency analysis for statistics-based text interpretation and a qualitative content analysis for category-oriented text interpretation [54] were equally applied in the thematic analysis. During the iterative process of coding, creating nodes and relationships, and aggregating the findings, a profound knowledge basis about smart mobility was created. The coding process of the thematic analysis was performed through open, axial, and selective coding [55,56]. Open coding was performed by carefully interrogating each publication's overall topic, findings, and contribution (first-order categories). This technique was also applied to reveal relationships between the sources. During axial coding, the nodes created in the open coding were refined and consolidated into higher categories based on their meanings (second-order categories). The highest level of abstraction was achieved during selective coding. The categories and relationships were further refined, compared, integrated, and grouped using this technique.

In line with the holistic approach of the smart mobility transition and the purpose of exploring both technical and organisational implications, a socio-technical system perspective [57] was adopted to guide and group the thematic analysis. Technical systems include goods, services, hardware/software facilities, and tasks/work [58], and related literature can provide insights into the technical infrastructure in smart mobility environments. Social systems include structures, behaviours, organisations, and cognitive and social processes [58], and analysing the literature on social systems can illuminate the systemic and organisational context in which road infrastructure is used in smart mobility environments.

For the thematic analysis, the software package NVIVO12 was used. Higher-level categories inevitably become quite general and can hide the richness of the underlying evidence they help to organise [38]. Using a rigour-analysing tool allows an iterative and traceable process of aggregating upwards and downwards.

A complete list of the literature reviewed can be obtained in Supplementary Materials.

4. Analysis and Results

The analysis was guided by the research objective of finding the implications of the smart mobility transition for road infrastructure provision. The descriptive analysis was executed to capture the degree of maturation of both the research field and its concepts and solutions. A thematic analysis was executed to capture and aggregate relevant topics and their overlaps/implications towards road infrastructure. The results, synthesised into implication pathways and a critical discussion on their practicality, were used to guide iterative sensemaking processes for building a conceptual model for the digital transformation of road infrastructure.

Figure 2 shows a summary of both the predefined descriptive and the evolved thematic topics of the analysis, where a parent node aggregates several child nodes from a lower level of the analysing hierarchy. For the thematic analysis, Figure 2 shows only the highest level of aggregation, whereas all the lower coding references towards a parent node are accessible/traceable in the analysing tool. As an example, the child node "organisation" (see Figure 2) has emerged through the axial coding process, representing "mobility ecosystems" and "business model innovation", which have emerged during open coding, as a parent node.

4.1. Descriptive Analysis

Each article in the sample was initially associated with predefined descriptive elements. Statistics related to these elements show smart mobility as a novel and fast-growing research topic, with [1] covering the governance of smart mobility as the most influential publication. The authorship and research fields are widely distributed. The areas of research are predominately technical (engineering, transportation, computer science) (see Figure 3), whereas multidisciplinary journals on sustainability and the environment are the most prominent outlet category. The methodological approaches were coded to understand whether the source was either studying an existing phenomenon empirically or proposing new frameworks and solutions conceptionally. Both methods were equally represented. As the conceptual sources regularly include a "proof of concept", a purely theoretical exploration was rare. Figure 3 shows selected results from the descriptive analysis. In Figure 2, all topics of the descriptive analysis are displayed.

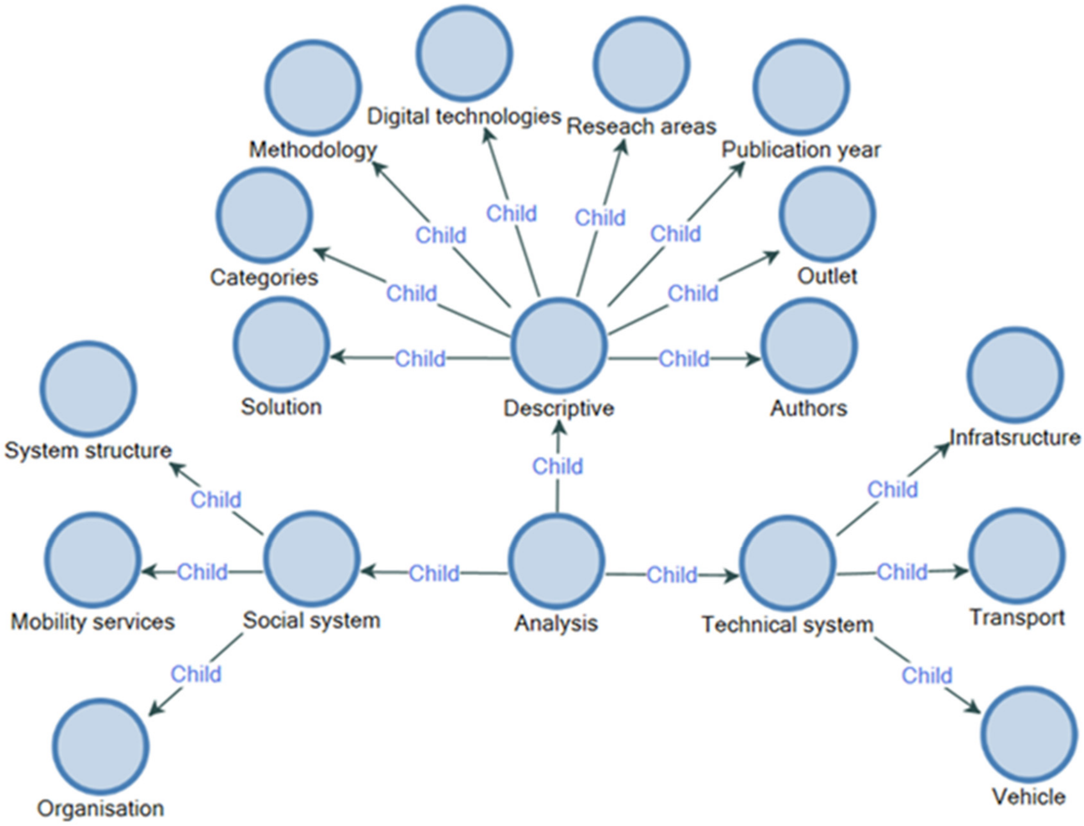

Figure 2. Summary of the topics.

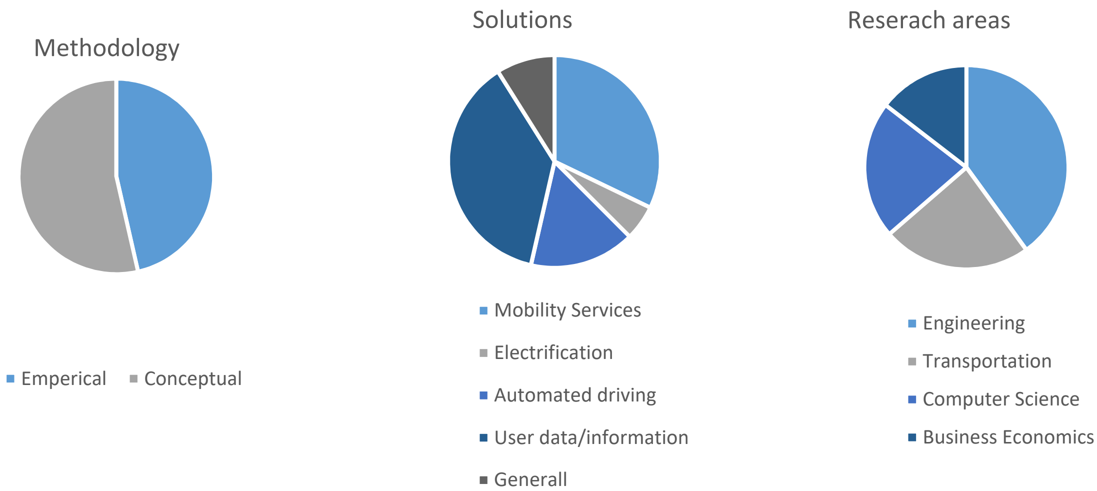

Figure 3. Descriptive analysis.

Digital technologies were used to link smart mobility with the concept of digital transformation while scoping the literature review. Consequently, multiple text searches and frequency queries were run to explore their appearances and relevance. Most of the literature on smart mobility solutions was sampled because the "internet of things" (IoT) appears as the primary digital technology used. The IoT describes connected physical objects that exchange data with other devices or systems. The IoT contributes to smart parking, smart charging, smart traffic control, smart routing, and smart road-lighting. It is proposed that the use of the IoT will increase further, as new applications are under development [59]. The literature also discusses challenges in handling an IoT flood and the discrimination of objects in the IoT [60]. Related to the infrastructure, roadside units (RSU) are placed to collect data and analyse them for traffic management [61] or vehicle-to-infrastructure (V2I) communication [6,62] and for automated and connected driving.

The complete text analysis revealed that "digital platforms", used in 46 of the 56 articles, are even more vital, as they appear as the underlying middleware for several digital technologies. As IoT implementations describe the technical, connecting physical objects, platforms describe businesses, connecting/including (previously unlinked) producers and consumers to solve a defined business problem or service demand. Smart mobility platforms can integrate several types of data (e.g., traffic data, behavioural data, open data). Regarding road infrastructure, these data include information about traffic congestion and flow, driving behaviour, accidents, road conditions, maintenance, local weather conditions, pollution, or special events. In the literature, platforms are mainly used to operate and maintain different kinds of vehicle fleets/transport modes and integrate them into a mobility service for the end user [63,64].

Additionally, "big data" are found to be essential. In all phases of smart mobility, users and "things" generate and access a massive amount of data. Static, historical data are not the main source for smart mobility solutions; they must cope with big data volume, variety, and veracity [65,66]. Once data are available and stored, "data analytics" can be used [65]. Data analytics and the upcoming blockchain technology used to render information transactions more secure and transparent [16,67] were seldom mentioned in the literature.

Besides the digital technologies used to scope the SLR, [68] summarises six enabling technologies that can facilitate the smooth adoption of smart mobility, whereof five are digital (IoT, blockchain, big data, artificial intelligence, geospatial technology, and clean energy).

4.2. Thematic Analysis

4.2.1. Technical System

The smart mobility literature argues for improved transport systems without large physical infrastructure investments by leveraging digital technologies [69,70]. Smart mobility is characterised by a wide range of technology deployments and aims to make all (existing) transportation modes equally accessible for citizens [71]. To achieve this, both infrastructure and vehicles are undergoing essential changes.

Measured by occupancy in the literature sample and by changes that are either ongoing or subject to significant R&D efforts, the electrification of vehicle fleets is a vital component of the smart mobility transition [1]. Driven by challenges to reduce CO2 emissions, the electrification of the transport system is a major goal for policymakers and the industry. In this context, the literature presents solutions for intelligent charging [72] and, even more, the management of overall electricity consumption (savings) and how to combine social networks, transport systems, and the power grid through IoT [73,74]. Satisfying the sustainability demand in smart mobility, a vehicle fleet using batteries can also be part of the electricity storage solutions for adopting widespread renewable energy production [1].

Besides the transition towards electric (battery) power, another vehicle-related transition is part of the literature—automated (AVs) and connected vehicles (CVs). AVs/CVs are described as a crucial part of smart mobility [62] and were designed to face the 90% human error rate that causes traffic accidents [75]. Meanwhile, various other benefits can be connected to AVs/CVs such as reduced congestion, vehicle emissions, traffic delays, and the improvement of people's accessibility [75–78]. In AVs, there is a differentiation between assisted driving, semi-automated driving, highly automated driving, and fully automated driving. It is expected that, in 2040, 30% of vehicles will have one of these functionalities [75]. As one article explores this topic related to possible door-to-door transportation by autonomous flying cars [79], the majority of this literature treats digital infrastructure that allows vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication and systems that can process this data and information [6,61,80]. Road safety issues and the possibility of performing other tasks while driving are the main purposes for these developments. Related literature on AV/CV solutions and their use of IoT sensing infrastructure already indicate implications for road infrastructure planning and engineering [4,7]. The installation of road site units and their connectivity (5G, LIDAR) must be assured [6,62,74,81].

Although the literature on both electrification and automated driving is widely conceptual, it may add a missing but crucial supplement. The solutions described in the literature are not related directly to the vehicle but facilitate that electrification and automatisation can be scaled and implemented in the transport system thanks to the existence of digital infrastructure, a large volume of mobility data, and the use of digital technologies [75].

Increasingly intelligent infrastructure is a key enabler for smart mobility [1]. By acquiring data from users and "things", intelligent infrastructure also provides information to optimise transport system performance and influence travel choices and behaviour. To capture data, sensors detect conditions, events, or changes in the road infrastructure or its environment. These sensors can be installed on the roadway, vehicles, or individuals. The extensive deployment of sensors and communication units is considered crucial in the literature, as mentioned in 48 of the 56 papers, but relies on adopting digital system architecture and components in the road infrastructure. Regardless of the sensor technology or the purpose of data collection, communication interfaces that support data transfers need to be established to achieve connectivity between the sensing devices and the data users [6,62]. According to [82], wireless communication is a fundamental driver of smart mobility concepts. Wireless sensor network technologies provide both the means of communication and the corresponding infrastructure. To obtain and integrate information from sensors and provide aggregated and intelligent views of raw data, the development of integration platforms is needed [83]. The literature frequently implicitly assumes that data are real-time, openly available, of good quality, and consumable. However, accessing data from anywhere, anytime, is challenging, and limited data accessibility can prevent the thorough mining of blossoming smart mobility initiatives [66]. The literature sample has little evidence on how the enormous demand for data (captured and transferred through sensors and connectivity devices) can be organised, not technically but organisationally. Figure 4 illustrates the steps that ensure a flow of data/information form-sensing at the infrastructure level towards data/information usage in the broader transport system.

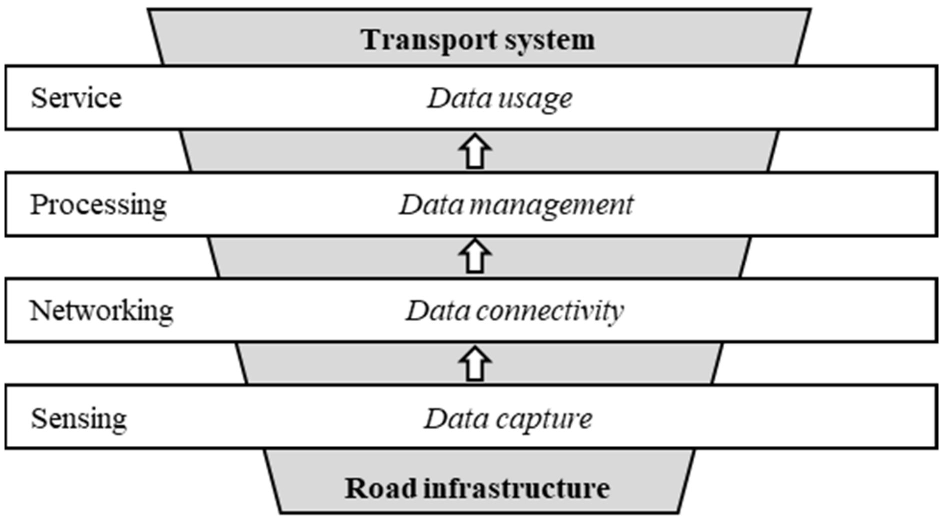

Figure 4. Required infrastructure to ensure data flow in smart mobility.

Another range of digital technology used in smart mobility literature is transport operations. Transport operation in smart mobility refers to systems for improving traffic quality, safety, and congestion [61]. Intelligent total transportation management systems use the IoT to integrate different vehicles and transport solutions with the infrastructure to solve traffic optimisation problems [84]. The authors of [85] analyse the theoretical and methodological foundations of smart logistic systems in practice to optimise future traffic flow management in the context of limited resources and a sharing economy.

Digital technologies in smart mobility also question the underlying principles of conventional transport planning, such as modelling approaches based on statistically forecasting traffic and single-mode transportation. Changes in vehicle technology and navigation solutions question travel-time minimisation through additional road infrastructure construction in favour of reasonable travel time with increased reliability [75,82]. Another study [86] presented a new platform-based planning tool to cope with the multimodal nature of future transport networks and the need for the flexible simulation of innovative transportation services, such as on-demand services. Putting people in the focus of transport planning instead of the vehicle is a major principle in transport planning for smart mobility [66].

For transport operations and transport planning solutions, the most conceptual research needs to be empirically tested, and the results obtained in the studies must be validated.

4.2.2. Social System

Through a systematic literature review, the authors of [61] examine the solutions available for traffic congestion and associated problems. More intelligent transport systems, both infrastructure-based and vehicle-based, were found to be the most suitable solution. These solutions are mainly concerned with those who interact directly with transport systems (e.g., operators and users) and are less focused on pursuing broader societal goals [61]. Definitions tend to agree that the concept of smart mobility involves technological components (such as vehicle electrification and intelligent infrastructure) but also goes beyond technology, as it is also concerned with improving sustainability goals, whether these are environmental, economic, or socially related [87].

All concepts and solutions described in the literature demand a certain degree of behavioural change from the transport user. Car dependency is recognised as the major obstacle to the smart mobility transition. Reducing car dependency increases the likelihood of changes to mobility services [88,89]. The literature offers multiple solutions such as ride-hailing [90], mobility-as-a-service (MaaS) [91], multimodal services [83], shared mobility [87], public transport [70], carpooling [81], mobility on demand [82], velomobility [92], and integrated systems that allow travellers to plan, book, and pay for trips through a single online interface [93]. This transition from a modal-centric towards a user-centric transport system is much more prominent in the literature than the earlier-mentioned transition of vehicles or infrastructure. It clearly includes the most empirical studies of all topics. These mobility services do not appear or are scalable without related changes to the technical system. Preferences in road space allocation and provision, transport mode inequality during transport planning, and the omitted provision of necessary data and information through the lack of intelligent infrastructure [1,60] can be directly linked to the success of mobility services.

Using digital technologies enables the outspread provision of mobility services, accelerating the transition from vehicle “ownership” to “usership”. Digital platforms, the IoT, and intensive big data processing bring together transport users and transport providers, in real time, on demand. The negative externalities related to car dependency, such as congestion, accidents, environmental issues, social exclusion, and obesity, which many states struggle to manage effectively, are exchanged for benefits in road safety and lower transport costs because the capital stock of the mobility system, primarily infrastructure, and vehicles, will be used much more efficiently [1,80]. Based on the empirical findings, the literature argues that behavioural changes require basic user acceptance of new mobility solutions at the technological, economic, and social levels [89,94]. Here, the literature provides solutions to increase this acceptance by offering more integrated and user-friendly solutions and rewarding systems.

A vital topic defining the smart mobility transition in the literature sample is decision-making and service development based on user-centred information. The solutions range from holistic frameworks (data-marked architectures) on data gathering, aggregation, reasoning, data analytics, access, and service delivery [64,65,67,95] to optimising decision-making for people's mobility choices [66], increased user-friendliness/service quality of the transport system [70,96], and smart mobility simulation and planning based on user participation [86,97]. User-centred and user-generated information is a major lead for more effective use of the existing infrastructure and estimation of future transport demands.

Concerning the organisational context, smart mobility concepts and solutions require cooperation between various actors and stakeholders. Hence, beyond digital technologies, a business ecosystem of multiple firms, organisations, and stakeholders collaborate to enable smart mobility [98]. The literature sample includes empirical [96] and conceptual studies [98], describing transportation ecosystems that integrate previously isolated sectors and stakeholders. These new ecosystems include transport infrastructure, transportation services, transport information, and financing/payment services involving the pre-journey, journey, and post-journey phases. These works adopt a broader system definition and include and integrate various data sources. New stakeholders from different sectors, industries, and time phases of the journey are added to the system, such as power grid developers for electrification [74], pedestrians and cyclists [60], and IT architecture and application developers [64,67,80,98]. According to [99], local citizens should also be involved at various levels and times through, for example, active involvement in the development of routes, stops, and bus schedules and in mobility planning processes [89,100].

Participating in this ecosystem requires changes to traditional business models and the public–private allocation of tasks [1]. It appears challenging to collect, integrate, and share data under existing business models, but the literature predicts possible new business models and different kinds of public–private partnerships. Empirical papers on this topic argue that the benefits would include new profitable markets and business models for businesses and renewed opportunities for the public sector as innovative service concepts and cooperation emerge [82]. To realise flexible, on-demand mobility solutions, the authors of [82] claim that, in the long run, public agencies may need to rethink their roles and consider opportunities for public–private partnerships and service agreements by changing focus from operating a particular transport mode towards integrated, intermodal, end-to-end mobility solutions.

Critical success factors in a business ecosystem are productivity, robustness, and the ability to create niches and opportunities for new firms [63]. Different ecosystem levels are defined in the literature. From a micro perspective, ecosystems can operate and maintain the vehicle fleet for mobility as a service [63]. On a macro level, an integrated smart mobility ecosystem contains real-time information systems, smart surveillance and road safety, automated toll collection, intelligent traffic management, and predictive road maintenance. Continuous monitoring and data collection combined with machine learning and artificial intelligence concepts enable predictive road maintenance in smart mobility [68].

The literature shows that digital platforms are critical in this context, as they provide the infrastructure for an ecosystem and facilitate resource integration and service development [63]. These platforms enable connections between previously unlinked demand- and supply-side market participants and facilitate their data exchange [8]. In addition, platforms are a crucial component of "servicing" the existing transport system. For decades, many organisations obtained competitive advantages through servitisation [101], by adding services to a product or replacing the product with a (digital) service. The participants in the smart mobility ecosystems rely on digital platforms, including users, suppliers, producers, and customers belonging to both public and private organisations. Platforms are intended to create knowledge from captured data and use this knowledge in (co-)value-creation processes. The integrative aspect of digital platforms is particularly relevant for aligning and stabilising the diversity of stakeholders, innovations, and technologies.

The sharing economy, particularly the sharing of cars, is evolving as a sustainable business model that promotes the value proposition of sharing over owning to reduce overall consumption and the use of resources. Competition between platforms can decrease costs for services and weaken a lock-in effect, which will have implications for public sector participation [66]. To govern these challenges, the authors of [1] propose that policies should promote open interfaces and data transferability, and the public sector should be aware of monopoly positions by single-platform owners.

Highlighting opportunities and challenges related to the smart mobility transition, the literature includes reviews on the trends [68] and definitions of the overall system transformation [3]. Besides an almost exclusively technologically positive viewpoint, the literature sporadically expounds on the problems of an "Internet of too many things" [59] or industry's economic interest in technology deployment [1]. On the other hand, [102] summarises the main benefits empirically, which also can be found as the predominant reasons for developing the respective smart mobility solution: environmental, economic, and social sustainability as well as health and security issues. As infrastructure is named as one part of the smart mobility transition, optimising the sustainability of the whole system may need to be preferred before optimising sustainability in only one part—in this case, road infrastructure provision.

5. Discussion

Identifying commonalities in the variety of arising transport solutions is critical to enabling infrastructure adaption, both technical and organisational. Isolated solutions have dominated the discourse on smart mobility, including only a few detached and unaligned needs, demands, and expectations towards road infrastructure provision. Scrutinising smart mobility literature on their use of digital technologies provides a valuable knowledge basis for discussing implications for road infrastructure provision, including concrete pathways for practitioners and a conceptual model for road infrastructure transformation for further research possibilities.

5.1. Impact on Road Infrastructure Development

Despite the essential advancement, the SLR reveals that smart mobility can appear immaturely to influence road infrastructure provision, but the recurring element of more sustainable solutions for long-lasting unsolved road transport issues makes smart mobility hard to ignore. On a macro level, sustainability is a common goal for road infrastructure provision and smart mobility. On a micro level, the road infrastructure sector uses digital technologies to optimise internal processes and coordination challenges in trying to achieve the highest efficiency [20]. Smart mobility builds a paradigm around economic, social, and environmental sustainability for the entire transport system as a precondition, trying to accomplish it with digital solutions. From this perspective, smart mobility can be seen as both a threat and a chance for the road infrastructure sector.

Investing in new physical road infrastructure means increasing the supply of road space, increasing the modal share of cars, and suppressing smart mobility innovations, which are not aligned with the developments described in the literature. Smart mobility solutions allocate road space differently than conventional road transport systems [3]. The increased effectiveness of existing road infrastructure through smart mobility solutions will reduce the demand for (new) physical road construction. Restricted infrastructure provision for motorised vehicles can be both a precondition and a result of this development. As an implication of the reduced demand for road infrastructure development, more competition in the industry may increase productivity, compensating for the decreasing volume and revenues in the sector. Reducing investment in the physical infrastructure offers new business areas and markets for intelligent, digital infrastructure [1]. A key enabler for smart mobility is the increased (upfront) investment in intelligent infrastructure [1]. Consequently, this can be included in the road infrastructure project scope as well as the mobilisation of ICT resources and competencies.

Smart mobility implies a contrasting approach to transport operation and planning. Besides optimising road operations that can result in lower physical infrastructure demand, road maintenance works are closely related to smart mobility transport operations. On a governance level, a key issue today is balancing the total infrastructure investments with (reduced) maintenance costs [1]. On a data management level, information about road maintenance works is demanded as "open data" for mobility platforms [66]. Continuous data collection and monitoring can be utilised for predictive maintenance, a key benefit of smart mobility according to [68]. A digital twin of the road infrastructure is presented as one solution for organising this data [103]. If this solution, as expected by [103], lowers maintenance costs, the road infrastructure sector may have a self-interest in deployment. If the benefits are more peripherical, such as providing mobility platform developers with open data, incentives for deployment may be limited.

The use of digital technologies allows the broad participation of various stakeholders in the road infrastructure planning process. The perception of building infrastructure with the citizen/user, not only for them, and sharing the same purpose and objective has emerged from the SLR. Modelling road infrastructure based on multiple data sources and simulating different design options and their consequences can have the consequence of building more appropriate infrastructure. Additionally, this may reduce the planning/engineering time due to increased public acceptance.

Table 1 contrasts traditional road infrastructure planning and engineering approaches [104] with those emerging from the SLR.

Table 1. Contrasting approaches to road infrastructure planning and engineering.

The Conventional Approach	The Smart Mobility Approach
Physical infrastructure	Digital infrastructure
Economic evaluation	Social, environmental, and economic evaluation
Single, motorised vehicle	All modes of transportation
Statistical traffic forecasting	Scenario development, visioning
Travel time minimisation	Reasonable time
Vehicle-centred	User-centred
Road project delivery	Data and service delivery
Project cost optimalisation	Total cost optimalisation
For the user	With the user

The paradigm of sustainability is important in terms of understanding the rationale behind road infrastructure planning and engineering in smart mobility, as many existing tools, methods, and processes cannot handle it. The major concerns over the physical dimension, and limited views on costs, transport modes, and deliveries (ref. Table 1), need to be addressed and replaced. Already a decade ago, [104] addressed two fundamental principles for sustainable mobility; transport needs to be handled as a valued activity instead of a derived demand where the value of the activity is created at the end of the travel, and minimalising the costs of travelling by minimising travel time needs to be balanced by "reasonable" travel times. Smart mobility finally gives concrete solutions for this early-formulated sustainable mobility paradigm.

In the smart mobility literature, digital technology is used for linking customers and mediating business processes that allow interactions and transactions in complex relationships among multiple stakeholders distributed in space and time. This fosters the formation of "value networks" [105]. Construction follows a linear value chain [106], where technology is used to transform inputs into outputs efficiently [107]. Value networks can provide the road infrastructure sector with an alternative framework to overcome performance challenges and initiate a transition to a people/user-centric perspective, as shown in other sectors and industries [108]. Value networks become useful for strategic positioning and building competitive advantages when user-centricity and digital technology deployment occur on both the demand and the supply side [109]. The mediating nature of value networks becomes useful to understand and agree on what to be "valued" and rewarded in developing transportation systems [109]. The SLR reveals that smart mobility addresses the user demand for sustainable transportation. A road infrastructure sector aiming to participate in such a value network may need to adopt sustainability as the most valuable performance indicator inside the entire value chain (client, contractor, sub-contractor/suppliers).

Digital platforms are the infrastructure for a value network that moves competition from a physical to a virtual plane [37]. Platforms can be used for projects, businesses, or industries and sectors [110], and platform thinking in the context of construction is emerging [111]. For road infrastructure development, a broad scope of applications is possible. By organising road infrastructure construction through digital platforms, data can be exchanged between project phases, different projects, supply chains, and inside the transportation network. This can considerably simplify collaboration, reduce transaction costs, and enable complementary innovation.

The concentration on construction efficiency has suppressed life-cycle considerations and possible optimisations in the planning and operation of infrastructure [112]. Platforms are a tool to pre-define and represent a physical asset and use and re-use the digital asset from a life-cycle perspective [111]. Product platforms, mainly used for buildings [113,114], can aid industrialisation efforts in road infrastructure developments.

Recently, the shift towards more cooperative client–supplier relationships (alliances, partnering) can be observed, also in road infrastructure development. To overcome insufficient understanding of the relationship dimension in the everyday practice of the involved actors [115], a shift in mindset towards platform thinking has been proposed [116]. As platforms are already present in construction, they can be enlarged from a focus on engineering platforms (mostly related to BIM) towards (re-)coordinating markets and building ecosystems and dynamic (digital) capabilities [117], also for road infrastructure networks.

The use of digital technologies in smart mobility fosters the provision of "services". The results of the SLR renew the attention on servitisation in construction and its transformative pathway for the sector, which has already been highlighted over a decade ago [118]. Predictive maintenance services are described as a part of smart mobility [68] and can be translated towards servicing the end user of road infrastructure. Using performance-based approaches for road infrastructure construction, contractors are compelled to deal with the end user and establish life-cycle considerations as key performance indicators for their projects [118]. More cooperative client–supplier relationships are seen as more suitable for shifting the mindset from products and production to a service-dominant value understanding [116].

5.2. Pathways and Conceptual Model for the Digital Transformation of Road Infrastructure

The synthesised implications for road infrastructure development can be viewed as pathways to create benefits for the road infrastructure sector and enable "better overall value" (a more sustainable transport system). The implications of smart mobility for road infrastructure development can be summarised as (1) new planning approaches, (2) adjusted building, (3) advanced operating, (4) additional deliverables, and, most importantly, (5) organisational changes.

Pathway (1) includes new planning tools, content, principals, and participants. It becomes obvious that the planning phase of road infrastructure that supports smart mobility must include new stakeholders and actors and uses different engineering principles and advanced planning tools that include these actors/stakeholders and principles as well as using data and information from the entire smart mobility ecosystem. Pathway (2) includes changes in providing physical and digital infrastructure. Smart mobility has a clear ambition to reduce the physical infrastructure asset, which includes both more effective use of the existing infrastructure and a reduction in new infrastructure demands.

Smart mobility is expected to improve the lane capacity, and the road width may shrink by a third due to AVs [12]. These reductions cannot be realised without simultaneously providing massive digital infrastructure [1]. Pathway (3) includes predictive maintenance, which is expected to increase the operational time of the road infrastructure while reducing costs related to maintenance efforts and increasing the lifetime of the infrastructure asset [12]. Pathway (4) includes data/information (various types of road-related information) and connectivity (V2I, 4/5G) as needing to be included as part of the delivery of road infrastructure provision. Here, a precondition is the "commodification of data/information" beyond a project value creation logic [20]. Finally, pathway (5) includes the appraisal of value networks and digital platforms as the main organisational precondition for road infrastructure to promote and participate in the smart mobility transition.

These five pathways can be used as drivers for the adjustment of the existing value understanding. Current practices in the construction sector [20] can hamper the implementation of these pathways. Moreover, the increasing use of digital technologies for transport solutions, the increasing availability of traffic/user data, and ongoing changes in transport behaviour and expectations, as described in the smart mobility literature, may lead to a broader value understanding in road infrastructure provision.

However, transforming a dominant system is a challenge for alternative approaches [119]. An important component of a socio-technical system transition is the presence of a new, desired system design. Smart mobility is described as a socio-technical system transition [1], and the related transformation of road infrastructure has been explored in this study. As a path forward, this study also provides a conceptual framework for the digital transformation of road infrastructure, including a new road infrastructure system design. The framework in Figure 5 integrates the dynamics of a socio-technical system transition [120] with the findings of this study.

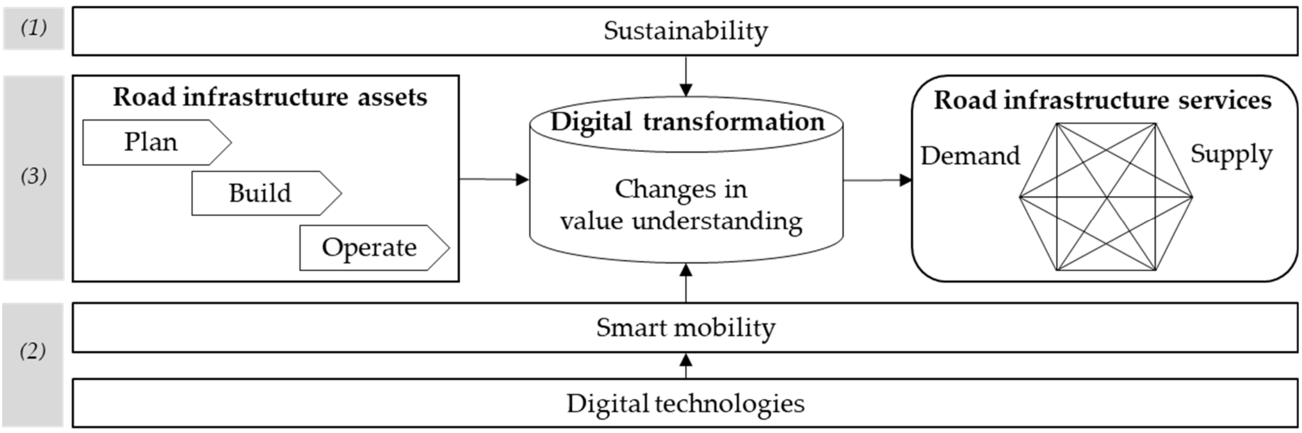

Figure 5. The conceptual model for the digital transformation of road infrastructure.

A socio-technical system consists of three main components: (1) the socio-technical landscape, (2) the alignment of innovations and technologies, and (3) the socio-technical system, pre- and post-transition. The demand for greater sustainability (1) and emerging smart mobility solutions enabled by digital technologies (2) create an opportunity for the digital transformation of road infrastructure (3). Through changes in the value understanding, by applying the five pathways for the digital transformation of road infrastructure, the existing system, based on physical assets and linear processes/production, can be transformed towards road infrastructure services, enabled by connecting supply and demand through networks and digital platforms.

From this model, research opportunities arise related to:

1. The challenging task of aligning and strengthening smart mobility solutions technically and organisationally.

2. The complexity of the digital transformation of a capital-intensive, long-lived physical infrastructure in a sector with well-established business models and value-creation processes.
3. The development of integrated digital platform ecosystems for road infrastructure provision.

Considering the current technical approach to the digital transformation of road infrastructure provision, three organisational research questions can be formulated:

(1) How should the governance of data related to road infrastructure be organised and executed?

Empirical studies are needed to investigate in detail how road infrastructure data are currently created, stored, and made available and address the gaps between the current and requested situations. Successional existing conceptual models and architectures of data orchestration need to be extended with frameworks on how they should be executed and by whom. Ensuring better data flow and utilisation will provide a foundation for digital transformation in the road infrastructure sector.

(2) How can value-creation paths for road infrastructure be changed?

Environmental improvements and effective, user-friendly service developments within the broader transportation network depend on infrastructure-related changes. Infrastructure development needs to be nudged towards these changes and measured in terms of its support for smart mobility. Studies at the organisational level of structural changes and organisational barriers for digital transformation in the sector will add useful knowledge and establish a basis for how digital value propositions, networks, and platforms can affect the required changes in value-creation paths.

(3) How does road infrastructure participate in platform ecosystems?

Drawing on the research agenda for digital platforms suggested by [35], and their question of how digital platforms transform industries, further research is needed on digital transformation in road infrastructure based on digital platforms. The conditions of platforms need to be decomposed from something "nice to have" or, worse, threatening profits and benefits in the existing value chain, into concepts and frameworks in which platforms are a necessity to capture value. Following [35,121–124], technical and organisational research on how platforms should be designed is needed.

6. Conclusions

Current policies and practices have not sufficiently reduced the environmental impact of road transportation. The predominant solution to handle traffic growth and congestion is the provision of additional physical road infrastructure assets. Smart mobility offers alternative approaches to handling traffic growth and congestion but depends on adapted road infrastructure. This study argues that the digital transformation of road infrastructure is needed for the transition towards a smarter—and with this, more sustainable—transport sector.

Both transport and construction have a broad research agenda towards digitalisation and sustainability but have been widely separated. By building a knowledge base on smart mobility, a demand-side perspective is adopted in this study as a unique approach to scrutinising the literature on smart mobility to identify implications for road infrastructure provision. In doing so, five pathways for road infrastructure development are proposed: (1) new planning approaches, (2) adjusted building, (3) advanced operating, (4) additional deliverables, and (5) organisational changes. The value proposition of sustainability is driving the smart mobility transition and needs to be adapted by the road infrastructure sector. This anticipates a change in the value understanding of digitalisation.

This study documents the societal and technical capacity of the smart mobility transition and develops a conceptual model for the related transformation of road infrastructure. Applying this model can enable infrastructure development to move from a project-/product-based value understanding, driven by short-term industry benefits, to a broader value understanding of providing suitable infrastructure that supports more sustainable transport systems.

The limitations of this study include the over- or under-representation of particular patterns or technologies related to the SLR methodology and the selection of search terms, databases, and exclusion/inclusion criteria.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15010210/s1, Table S1: List of literature sample.

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References

1. Docherty, I.; Marsden, G.; Anable, J. The governance of smart mobility. *Transp. Res. Part A Policy Pr.* **2018**, *115*, 114–125. [CrossRef]
2. Freitas, A.; Brito, L.; Baras, K.; Silva, J. Smart mobility: A survey. In Proceedings of the Internet of Things for the Global Community, IoTGC 2017, Funchal, Portugal, 10–13 July 2017. [CrossRef]
3. Nikitas, A.; Michalakopoulou, K.; Njoya, E.T.; Karampatzakis, D. Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era. *Sustainability* **2020**, *12*, 2789. [CrossRef]
4. Wallace, S.; Lăzăroiu, G. Predictive control algorithms, real-world connected vehicle data, and smart mobility technologies in intelligent transportation planning and engineering. *Contemp. Read. Law Soc. Justice* **2021**, *13*, 79–92. [CrossRef]
5. Khan, S.M.; Chowdhury, M.; Morris, E.A.; Deka, L. Synergizing Roadway Infrastructure Investment with Digital Infrastructure for Infrastructure-Based Connected Vehicle Applications: Review of Current Status and Future Directions. *J. Infrastruct. Syst.* **2019**, *25*, 4. [CrossRef]
6. Bučko, B.; Michálek, M.; Papierniková, K.; Zábovská, K. Smart Mobility and Aspects of Vehicle-to-Infrastructure: A Data Viewpoint. *Appl. Sci.* **2021**, *11*, 10514. [CrossRef]
7. Wang, P.; McKeever, B.; Chan, C.Y. Automated Vehicles Industry Survey of Transportation Infrastructure Needs. *Transp. Res. Rec.* **2022**, *2676*, 554–569. [CrossRef]
8. van Alstyne, M.W.; Parker, G.G.; Choudary, S.P. Pipelines, platforms, and the new rules of strategy. *Harv. Bus. Rev.* **2016**, *94*, 4.
9. Whyte, J. How digital information transforms project delivery models. *Proj. Manag. J.* **2019**, *50*, 177–194. [CrossRef]
10. Barbosa, F.; Woetzel, J.; Mischke, J. Reinventing Construction: A Route of Higher Productivity. McKinsey&Company. 2017. Available online: http://dln.jaipuria.ac.in:8080/jspui/bitstream/123456789/2898/1/MGI-Reinventing-Construction-Full-report.pdf (accessed on 3 July 2022).
11. Glass, J.; Bygballe, L.E.; Hall, D. *Call for Papers Transforming Construction: The Multi-Scale Challenges of Changing and Innovating in Construction*; University College London: London, UK, 2020.
12. Stern, S.; Kirchherr, J.; Valtuena-Ramos, G.; Reitz, F.; Flyvbjerg, B.; Budzier, A.; Agard, K. *Road Work Ahead: The Emerging Revolution in the Road Construction Industry*; White Paper; McKinsey & Company: Atlanta, GA, USA, 2021.
13. Noy, K.; Givoni, M. Is 'smart mobility' sustainable? Examining the views and beliefs of transport's technological entrepreneurs. *Sustainability* **2018**, *10*, 422. [CrossRef]
14. Anagnostopoulou, E.; Bothos, E.; Magoutas, B.; Schrammel, J.; Mentzas, G. Persuasive technologies for sustainable mobility: State of the art and emerging trends. *Sustainability* **2018**, *10*, 2128. [CrossRef]
15. Ruhrort, L. Reassessing the role of shared mobility services in a transport transition: Can they contribute the rise of an alternative socio-technical regime of mobility? *Sustainability* **2020**, *12*, 8253. [CrossRef]
16. Karger, E.; Jagals, M.; Ahlemann, F. Blockchain for Smart Mobility-Literature Review and Future Research Agenda. *Sustainability* **2021**, *13*, 13268. [CrossRef]
17. Jones, K.; Davies, A.; Mosca, L.; Whyte, J.; Glass, J. Changing Business Models: Implications for Construction. *Transform. Constr. Netw. Plus Dig. Ser.* **2019**. Available online: https://www.ucl.ac.uk/bartlett/construction/sites/bartlett/files/digest_-_changing_business_models_-_implications_for_construction.pdf (accessed on 24 November 2022).
18. Kvålshaugen, R.; Bygballe, L.E. Transformasjon av den Norske Bygg-, Anleggs-og Eiendomsnaeringen. Oslo. 2021. Available online: https://www.idunn.no/pof (accessed on 15 September 2022).
19. Ernstsen, S.N.; Whyte, J.; Thuesen, C.; Maier, A. How Innovation Champions Frame the Future: Three Visions for Digital Transformation of Construction. *J. Constr. Eng. Manag.* **2020**, *147*, 05020022. [CrossRef]
20. Çıdık, M.S.; Boyd, D. Value implication of digital transformation: The impact of the commodification of information. *Constr. Manag. Econ.* **2022**, *40*, 903–917. [CrossRef]
21. Criado-Perez, C.; Shinkle, G.A.; Höllerer, M.A.; Sharma, A.; Collins, C.; Gardner, N.; Haeusler, M.H.; Pan, S. Digital Transformation in the Australian AEC Industry: Prevailing Issues and Prospective Leadership Thinking. *J. Constr. Eng. Manag.* **2022**, *148*, 05021012. [CrossRef]

22. Sundnes, K.O. The transectional structure of society: The basic societal functions. *Scand. J. Public Health* **2014**, *42* (Suppl. 14), 36–47. [CrossRef]
23. Mattioli, G.; Roberts, C.; Steinberger, J.K.; Brown, A. The political economy of car dependence: A systems of provision approach. *Energy Res. Soc. Sci.* **2020**, *66*, 101486. [CrossRef]
24. Geels, F. The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technol. Anal. Strat. Manag.* **2005**, *17*, 445–476. [CrossRef]
25. Geels, F. A socio-technical analysis of low-carbon transitions: Introducing the multi-level perspective into transport studies. *J. Transp. Geogr.* **2012**, *24*, 471–482. [CrossRef]
26. Lyons, G. Getting smart about urban mobility–Aligning the paradigms of smart and sustainable. *Transp. Res. Part A Policy Pr.* **2018**, *115*, 4–14. [CrossRef]
27. Asselin-Miller, N.; Biedka, M.; Gibson, G.; Kirsch, F.; Hill, N.; White, B.; Uddin, K. Study on the Deployment of C-ITS in Europe: Final Report; Report for DG MOVE MOVE/C, 3, 2014-794 2016. Available online: https://transport.ec.europa.eu/system/files/2016-10/2016-c-its-deployment-study-final-report.pdf (accessed on 24 November 2022).
28. German Federal Statistical Office. Road Transport: EU-Wide Carbon Dioxide Emissions Have Increased by 24% Since 1990. 2022. Available online: https://www.destatis.de/Europa/EN/Topic/Environment-energy/CarbonDioxideRoadTransport.html (accessed on 20 September 2022).
29. Eurostat. Greenhouse Gas Emissions by Source Sector. *EEA*. 10 June 2022. Available online: https://ec.europa.eu/eurostat/databrowser/view/ENV_AIR_GGE__custom_1256039/bookmark/table?lang=en&bookmarkId=1ffd5837-18ba-4e68-9634-1eaf2d6d4023 (accessed on 20 September 2022).
30. Mangiaracina, R.; Perego, A.; Salvadori, G.; Tumino, A. A comprehensive view of intelligent transport systems for urban smart mobility. *Int. J. Logist. Res. Appl.* **2017**, *20*, 39–52. [CrossRef]
31. Vreeswijk, J.; Wilmink, I.; Gilka, P.; Vernet, G.; Andreone, L.; Pandazis, J.C.; Themann, P.; Mathias, P. C-ITS implementation issues: Barriers and possible solutions. In Proceedings of the 10th ITS European Congress, Helsinki, Finland, 16–19 June 2014.
32. Brenner, S.W. *Law in an Era of "Smart" Technology*; Oxford University Press, Inc.: New York, NY, USA, 2007.
33. Eggers, B.; Fishman, T.; Viechnicki, P.; Khuperkar, A. *Smart Mobility Reducing Congestion and Fostering Faster, Greener, and Cheaper Transportation Options*; Deloitte University Press: New York, NY, USA, 2022. Available online: http://dupress.com/articles/smart-mobility-trends (accessed on 20 September 2022).
34. Bharadwaj, A.; el Sawy, O.A.; Pavlou, P.A.; Venkatraman, N. Digital Business Strategy: Toward a Next Generation of Insights. *MIS Q.* **2013**, *37*, 471–482. [CrossRef]
35. de Reuver, M.; Sørensen, C.; Basole, R.C. The Digital Platform: A Research Agenda. *J. Inf. Technol.* **2018**, *33*, 124–135. [CrossRef]
36. Sebastian, I.M.; Moloney, K.G.; Ross, J.W.; Fonstad, N.O.; Beath, C.; Mocker, M. How big old companies navigate digital transformation. *MIS Q. Exec.* **2017**, *16*, 197–213.
37. Vial, G. Understanding digital transformation: A review and a research agenda. *J. Strateg. Inf. Syst.* **2019**, *28*, 118–144. [CrossRef]
38. Matt, C.; Hess, T.; Benlian, A. Digital Transformation Strategies. *Bus. Inf. Syst. Eng.* **2015**, *57*, 339–343. [CrossRef]
39. Hess, T.; Benlian, A.; Matt, C.; Wiesböck, F. Options for formulating a digital transformation strategy. *MIS Q. Exec.* **2016**, *15*, 123–139. [CrossRef]
40. Rogers, D.L. *The Digital Transformation Playbook*; Columbia University Press: New York, NY, USA, 2016. [CrossRef]
41. Kane, G.C.; Palmer, D.; Phillips, A.N.; Kiron, D.; Buckley, N. *Strategy, not Technology, Drives Digital Transformation*; MIT Sloan Management Review and Deloitte University Press: Cambridge, CA, USA, 2015.
42. Porter, M.E.; Heppelmann, J.E. How Smart, Connected Products Are Transforming Competition. *Harv. Bus. Rev.* **2014**, *92*, 64–88.
43. Adekunle, S.A.; Aigbavboa, C.O.; Ejohwomu, O.; Adekunle, E.A.; Thwala, W.D. Digital transformation in the construction industry: A bibliometric review. *J. Eng. Des. Technol.* **2021**. *ahead-of-print*. [CrossRef]
44. Olanipekun, A.O.; Sutrisna, M. Facilitating Digital Transformation in Construction—A Systematic Review of the Current State of the Art. *Front. Built. Environ.* **2021**, *7*, 96. [CrossRef]
45. Verhoef, P.C.; Broekhuizen, T.; Bart, Y.; Bhattacharya, A.; Dong, J.Q.; Fabian, N.; Haenlein, M. Digital transformation: A multidisciplinary reflection and research agenda. *J. Bus. Res.* **2021**, *122*, 889–901. [CrossRef]
46. Leviäkangas, P. Digitalisation of Finland's transport sector. *Technol. Soc.* **2016**, *47*, 1–15. [CrossRef]
47. Woodhead, R.; Stephenson, P.; Morrey, D. Digital construction: From point solutions to IoT ecosystem. *Autom. Constr.* **2018**, *93*, 35–46. [CrossRef]
48. Han, T.; Ma, T.; Fang, Z.; Zhang, Y.; Han, C. A BIM-IoT and intelligent compaction integrated framework for advanced road compaction quality monitoring and management. *Comput. Electr. Eng.* **2022**, *100*, 107981. [CrossRef]
49. Widyatmoko, I. Digital transformation to improve quality, efficiency and safety in construction of roads incorporating recycled materials. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *599*, 012093. [CrossRef]
50. IPCC. *Climate Change 2021: The Physical Science Basis*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2021; p. 2391. [CrossRef]
51. Wolfswinkel, J.F.; Furtmueller, E.; Wilderom, C.P.M. Using grounded theory as a method for rigorously reviewing literature. *Eur. J. Inf. Syst.* **2013**, *22*, 45–55. [CrossRef]
52. van Wee, B.; Banister, D. How to Write a Literature Review Paper? *Transp. Rev.* **2015**, *36*, 278–288. [CrossRef]

53. Denyer, D.; Tranfeld, D. Producing a Systematic Review. In *Sage Handbook of Organizational Research Methods*; Sage Publications Ltd.: London, UK, 2009; pp. 671–689. Available online: https://psycnet.apa.org/record/2010-00924-039 (accessed on 4 February 2020).
54. Berelson, B. Content Analysis in Communication Research. 1952. Available online: https://psycnet.apa.org/record/1953-07730-000 (accessed on 11 July 2022).
55. Strauss, A.; Corbin, J. *Basics of Qualitative Research*, 2nd ed.; Saga Publications, Inc.: Chicago, IL, USA, 1998.
56. Corbin, J.M.; Strauss, A. Grounded theory research: Procedures, canons, and evaluative criteria. *Qual. Sociol.* **1990**, *13*, 3–21. [CrossRef]
57. Geels, F.W. Socio-Technical Transitions to Sustainability. *Oxf. Res. Encycl. Environ. Sci.* **2018**. [CrossRef]
58. Oosthuizen, R.; Pretorius, L. Assessing the impact of new technology on complex sociotechnical systems. *S. Afr. J. Ind. Eng.* **2016**, *27*, 15–29. [CrossRef]
59. Xu, L. Internet of Too Many Things in Smart Transport: The Problem, the Side Effects and the Solution. ieeexplore.ieee.org. 2018. Available online: https://ieeexplore.ieee.org/abstract/document/8506609/ (accessed on 21 February 2020).
60. Behrendt, F. Mobility and data: Cycling the utopian Internet of Things. *Mobilities* **2020**, *15*, 81–105. [CrossRef]
61. Ahmed, A.; Fragonara, L. Adaptive intelligent traffic control system for improving traffic quality and congestion in smart cities. *Int. J. Qual. Res.* **2021**, *15*, 139–154. [CrossRef]
62. Kim, K.; Kim, J.S.; Jeong, S.; Park, J.H.; Kim, H.K. Cybersecurity for autonomous vehicles: Review of attacks and defense. *Comput. Secur.* **2021**, *103*, 102150. [CrossRef]
63. Pulkkinen, J.; Jussila, J.; Partanen, A.; Trotskii, I.; Laiho, A. Smart Mobility: Services, Platforms and Ecosystems. *Technol. Innov. Manag. Rev.* **2019**, *9*, 15–24. [CrossRef]
64. Kawasaki, A. Fujitsu's approach to smart mobility. *Fujitsu Sci. Tech. J.* **2015**, *51*, 3–7.
65. Badii, C.; Bellini, P.; Cenni, D.; Difino, A.; Nesi, P.; Paolucci, M. Analysis and assessment of a knowledge based smart city architecture providing service APIs. *Future Gener. Comput. Syst.* **2017**, *75*, 14–29. [CrossRef]
66. del Vecchio, P.; Secundo, G.; Maruccia, Y.; Passiante, G. A system dynamic approach for the smart mobility of people: Implications in the age of big data. *Technol. Soc. Chang.* **2019**, *149*, 119771. [CrossRef]
67. López, D.; Farooq, B. A multi-layered blockchain framework for smart mobility data-markets. *Transp. Res. Part C Emerg. Technol.* **2020**, *111*, 588–615. [CrossRef]
68. Paiva, S.; Ahad, M.A.; Tripathi, G.; Feroz, N.; Casalino, G. Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges. *Sensors* **2021**, *21*, 2143. [CrossRef]
69. Bucchiarone, A.; Battisti, S.; Marconi, A.; Maldacea, R.; Ponce, D.C. Autonomous Shuttle-as-a-Service (ASaaS): Challenges, Opportunities, and Social Implications. *IEEE Trans. Intell. Transp. Syst.* **2021**, *22*, 3790–3799. [CrossRef]
70. Falco, E.; Malavolta, I.; Radzimski, A.; Ruberto, S.; Iovino, L.; Gallo, F. Smart City L'Aquila: An Application of the 'Infostructure' Approach to Public Urban Mobility in a Post-Disaster Context. *J. Urban Technol.* **2018**, *25*, 99–121. [CrossRef]
71. Dell'Era, C.; Altuna, N.; Verganti, R. Designing radical innovations of meanings for society: Envisioning new scenarios for smart mobility. *Creat. Innov. Manag.* **2018**, *27*, 387–400. [CrossRef]
72. Karpenko, A.; Kinnunen, T.; Madhikermi, M.; Robert, J.; Främling, K.; Dave, B.; Nurminen, A. Data Exchange Interoperability in IoT Ecosystem for Smart Parking and EV Charging. *Sensors* **2018**, *18*, 4404. [CrossRef]
73. Ptak, A. Smart City Management in the Context of Electricity Consumption Savings. *Energies* **2021**, *14*, 6170. [CrossRef]
74. Amini, M.H.; Mohammadi, J.; Kar, S. Distributed Holistic Framework for Smart City Infrastructures: Tale of Interdependent Electrified Transportation Network and Power Grid. *IEEE Access* **2019**, *7*, 157535–157554. [CrossRef]
75. Mahrez, Z.; Sabir, E.; Badidi, E. Smart urban mobility: When mobility systems meet smart data. *IEEE Trans. Intell. Transp. Syst.* **2021**. Available online: https://ieeexplore.ieee.org/abstract/document/9453170/?casa_token=X9HKEDdBQYgAAAAA:t__lnw_7xR7RVChnmtHmqy76m6NtMXIu8nFZyU85Vw6xGxn55g7n-14HGjh2uzc_K7LWpJgkQQ (accessed on 4 July 2022).
76. Bagloee, S.A.; Tavana, M.; Asadi, M.; Oliver, T. Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies. *J. Mod. Transp.* **2016**, *24*, 284–303. [CrossRef]
77. Johnson, E.; Nica, E. Connected vehicle technologies, autonomous driving perception algorithms, and smart sustainable urban mobility behaviors in networked transport systems. *Contemp. Read. Law Soc. Justice* **2021**, *13*, 37–50. [CrossRef]
78. Lăzăroiu, G.; Harrison, A. Internet of Things Sensing Infrastructures and Data-driven Planning Technologies in Smart Sustainable City Governance and Management. *Geopolit. Hist. Int. Relat.* **2021**, *13*, 23–36. [CrossRef]
79. Gyula, M. Smart mobility solutions in smart cities. *Interdiscip. Descr. Complex Syst. INDECS* **2022**, *20*, 37–43. [CrossRef]
80. Celesti, A.; Galletta, A.; Carnevale, L.; Fazio, M.; Lay-Ekuakille, A.; Villari, M. An IoT cloud system for traffic monitoring and vehicular accidents prevention based on mobile sensor data processing. *IEEE Sens. J.* **2018**, *18*, 4795–4802. [CrossRef]
81. Anthopoulos, L.; Tzimos, D. Carpooling platforms as smart city projects: A bibliometric analysis and systematic literature review. *Sustainability* **2021**, *13*, 10680. [CrossRef]
82. Liyanage, S.; Dia, H.; Abduljabbar, R.; Bagloee, S.A. Flexible mobility on-demand: An environmental scan. *Sustainability* **2019**, *11*, 1262. [CrossRef]
83. Al-Rahamneh, A.; Astrain, J.J.; Villadangos, J.; Klaina, H.; Guembe, I.P.; Lopez-Iturri, P.; Falcone, F. Enabling Customizable Services for Multimodal Smart Mobility with City-Platforms. *IEEE Access* **2021**, *9*, 41628–41646. [CrossRef]
84. Nguyen, D.D.; Rohács, J.; Rohács, D.; Boros, A. Intelligent total transportation management system for future smart cities. *Appl. Sci.* **2020**, *10*, 8933. [CrossRef]

85. Savin, G. The smart city transport and logistics system: Theory, methodology and practice. *Upr./Manag.* **2021**, *12*, 67–86. [CrossRef]
86. Azevedo, C.L.; Deshmukh, N.M.; Marimuthu, B.; Oh, S.; Marczuk, K.; Soh, H.; Basak, K.; Toledo, T.; Peh, L.-S.; Ben-Akiva, M.E. Simmobility short-term: An integrated microscopic mobility simulator. *Transp. Res. Rec.* **2017**, *2622*, 13–23. [CrossRef]
87. Castellanos, S.; Grant-Muller, S.; Wright, K. Technology, transport, and the sharing economy: Towards a working taxonomy for shared mobility. *Transp. Rev.* **2021**, *42*, 318–336. [CrossRef]
88. Pangbourne, K.; Mladenović, M.N.; Stead, D.; Milakis, D. Questioning mobility as a service: Unanticipated implications for society and governance. *Transp. Res. Part A Policy Pr.* **2020**, *131*, 35–49. [CrossRef]
89. Semanjski, I.; Aguirre, A.J.L.; de Mol, J.; Gautama, S. Policy 2.0 platform for mobile sensing and incentivized targeted shifts in mobility behavior. *Sensors* **2016**, *16*, 1035. [CrossRef]
90. Acheampong, R.A.; Siiba, A.; Okyere, D.K.; Tuffour, J.P. Mobility-on-demand: An empirical study of internet-based ride-hailing adoption factors, travel characteristics and mode substitution effects. *Transp. Res. Part C Emerg. Technol.* **2020**, *115*, 102638. [CrossRef]
91. Arnaoutaki, K.; Bothos, E.; Magoutas, B.; Aba, A.; Esztergár-Kiss, D.; Mentzas, G. A Recommender System for Mobility-as-a-Service Plans Selection. *Sustainability* **2021**, *13*, 8245. [CrossRef]
92. Behrendt, F. Why cycling matters for Smart Cities. Internet of Bicycles for Intelligent Transport. *J. Transp. Geogr.* **2016**, *56*, 157–164. [CrossRef]
93. Butler, L.; Yigitcanlar, T.; Paz, A. Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. *Cities* **2021**, *109*, 103036. [CrossRef]
94. Ahmed, W.; Hizam, S.M.; Sentosa, I.; Akter, H.; Yafi, E.; Ali, J. Predicting IoT service adoption towards smart mobility in Malaysia: SEM-neural hybrid pilot study. *Int. J. Adv. Comput. Sci. Appl.* **2020**, *11*, 524–535. [CrossRef]
95. Mirri, S.; Prandi, C.; Salomoni, P.; Callegati, F.; Melis, A.; Prandini, M. A Service-Oriented Approach to Crowdsensing for Accessible Smart Mobility Scenarios. *Mob. Inf. Syst.* **2016**, *2016*, 2821680. [CrossRef]
96. Longo, A.; Zappatore, M.; Navathe, S.B. The unified chart of mobility services: Towards a systemic approach to analyze service quality in smart mobility ecosystem. *J. Parallel Distrib. Comput.* **2019**, *127*, 118–133. [CrossRef]
97. Rocha, N.P.; Bastardo, R.; Pavão, J.; Santinha, G.; Rodrigues, M.; Rodrigues, C.; Queirós, A.; Dias, A. Smart Cities' Applications to Facilitate the Mobility of Older Adults: A Systematic Review of the Literature. *Appl. Sci.* **2021**, *11*, 6395. [CrossRef]
98. Faber, A.; Rehm, S.V.; Hernandez-Mendez, A.; Matthes, F. Modeling and visualizing smart city mobility business ecosystems: Insights from a case study. *Information* **2018**, *9*, 270. [CrossRef]
99. Porru, S.; Misso, F.E.; Pani, F.E.; Repetto, C. Smart mobility and public transport: Opportunities and challenges in rural and urban areas. *J. Traffic Transp. Eng. (Engl. Ed.)* **2020**, *7*, 88–97. [CrossRef]
100. Semanjski, I.; Bellens, R.; Gautama, S.; Witlox, F. Integrating big data into a sustainable mobility policy 2.0 planning support system. *Sustainability* **2016**, *8*, 1142. [CrossRef]
101. Vandermerwe, S.; Rada, J. Servitization of business: Adding value by adding services. *Eur. Manag. J.* **1988**, *6*, 314–324. [CrossRef]
102. Mohammadian, D.H.; Rezaie, F. Blue-Green Smart Mobility Technologies as Readiness for Facing Tomorrow's Urban Shock toward the World as a Better Place for Living (Case Studies: Songdo and Copenhagen). *Technologies* **2020**, *8*, 39. [CrossRef]
103. el Marai, O.; Taleb, T.; Song, J. Roads Infrastructure Digital Twin: A Step Toward Smarter Cities Realization. *IEEE Netw.* **2021**, *35*, 136–143. [CrossRef]
104. Banister, D. The sustainable mobility paradigm. *Transp. Policy (Oxf.)* **2008**, *15*, 73–80. [CrossRef]
105. Stabell, C.B.; Fjeldstad, Ø.D. Configuring Value for Competative Advantage: On Chains, Shops, and Networks. *Strateg. Manag. J.* **1998**, *19*, 413–437. [CrossRef]
106. Bygballe, L.E.; Jahre, M. Balancing value creating logics in construction. *Constr. Manag. Econ.* **2009**, *27*, 695–704. [CrossRef]
107. Porter, M.E. *The Competitive Advantage: Creating and Sustaining Superior Performance*; Free Press: New York, NY, USA, 1985.
108. Meggitt, D.; Sarri, C.; Evans, L. Using value networks to boost construction performance. *Proc. Inst. Civ. Eng. Civ. Eng.* **2012**, *165*, 11–17. [CrossRef]
109. Leviäkangas, P.; Öörni, R. From business models to value networks and business ecosystems–What does it mean for the economics and governance of the transport system? *Util Policy* **2020**, *64*, 101046. [CrossRef]
110. Gawer, A. Bridging differing perspectives on technological platforms: Toward an integrative framework. *Res. Policy* **2014**, *43*, 1239–1249. [CrossRef]
111. Mosca, L.; Jones, K.; Davies, A.; Whyte, J.; Glass, J. Platform Thinking for Construction. Transforming Construction Network Plus, Digest Series, No. 2. 2020. Available online: https://www.ucl.ac.uk/bartlett/construction/sites/bartlett/files/digest-platform-thinking-for-construction.pdf (accessed on 5 October 2021).
112. Goger, G.; Bisenberger, T. Digitalization in infrastructure construction–Developments in construction operations. *Geomech. Und Tunn.* **2020**, *13*, 165–177. [CrossRef]
113. Jansson, G.; Johnsson, H.; Engström, D. Platform use in systems building. *Constr. Manag. Econ.* **2014**, *32*, 70–82. [CrossRef]
114. Maxwell, D.W. Platforms for industrialised construction–lessons from Sweden. In Proceedings of the 50th International Concerace of the Architectual Science Assosiation, Adelaide, Australia, 7–9 December 2016; pp. 785–794.
115. Bygballe, L.E.; Jahre, M.; Swärd, A. Partnering relationships in construction: A literature review. *J. Purch. Supply Manag.* **2010**, *16*, 239–253. [CrossRef]

116. Jacobsson, M.; Roth, P. Towards a shift in mindset: Partnering projects as engagement platforms. *Constr. Manag. Econ.* **2014**, *32*, 419–432. [CrossRef]
117. Chan, P.W. Construction in the platform society: New directions for construction management. *Management* **2022**, *396*, 405.
118. Straub, A.D. Competences of maintenance service suppliers servicing end-customers. *Constr. Manag. Econ.* **2010**, *28*, 1187–1195. [CrossRef]
119. Geels, F.W.; Schot, J. Typology of sociotechnical transition pathways. *Res Policy* **2007**, *36*, 399–417. [CrossRef]
120. Geels, F.W.; Schot, J. The dynamics of transitions: A socio-technical perspective. In *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*; Grin, J., Rotmans, J., Schot, J., Eds.; Routledge: New York, NY, USA; Abingdon, UK, 2010; pp. 11–104.
121. Gawer, A. *Platforms, Markets and Innovation: An Introduction*; Edward Elgar Publishing Ltd.: Cheltenham, UK, 2009. [CrossRef]
122. Gawer, A.; Cusumano, M.A. How Companies Become Platform Leaders. *MIT Sloan Manag. Rev.* **2008**, *49*, 68–75.
123. Gawer, A.; Cusumano, M.A. Industry platforms and ecosystem innovation. *J. Prod. Innov. Manag.* **2014**, *31*, 417–433. [CrossRef]
124. Cusumano, M.A.; Gawer, A.; Yoffie, D.B. *The Business of Platforms*; HarperCollins Publishers Inc.: New York, NY, USA, 2019; Volume 1.