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Bernsteiner, Johannes; Ninan, Johan

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Actor-networks in sustainable transport transformation: the case of the Catharijnesingel restoration

Johannes Bernsteiner

PhD Student, Institute of Urbanism, Graz University of Technology, Graz, Austria (Orcid:0009-0009-0951-0879) (corresponding author: johannes@bernsteiner.com)

Johan Ninan

Assistant Professor, Faculty of Civil Engineering and Geosciences, Technische Universiteit Delft, Delft, Netherlands (Orcid:0000-0002-0255-0511) (corresponding author: J.Ninan@tudelft.nl)



As cities evolve, navigating the complex interplay between social and technical elements is crucial for achieving sustainable urban development. This paper uses a case-study approach and applies actor-network theory (ANT) to understand the sociotechnical complexities of urban transformation, with a specific focus on transport projects at the municipal level. ANT serves as a qualitative analytical framework to investigate the successful restoration of Catharijnesingel in Utrecht. Interviews with ten field experts have provided valuable insights into the transformation process, revealing the underlying paradigms at play. Specifically, this study used Michel Callon's (1984) concept of translation to analyze how agency is enacted in decision-making processes. By focusing this research on actor-networks related to the theme of sustainable transport, the study has identified five transformation mechanisms involved in removing the 20th-century city highway and restoring the original canal, offering valuable lessons for similar projects in various contexts. This study contributes to the existing ANT literature by presenting a robust framework for analyzing actor-networks in transport infrastructure transformation projects, thereby opening new avenues for future research and practical applications in urban planning.

Keywords: actor-network theory/infrastructure planning/roads & highways/sustainable development/transport planning/UN SDG 11: Sustainable cities and communities/urban regeneration/waterways & canals

Notation

ANT	Actor-network theory
OPP	Obligatory passage point
STS	Science and technology studies

1. Introduction

Emerging from the broader discipline of sustainable urban development, sustainable transport infrastructure is designed to fulfill present transportation needs while ensuring that future generations can also meet theirs (Gallo and Marinelli, 2020). The transition toward transportation systems that are environmentally friendly and socially inclusive necessitates a significant overhaul and adaptation of last-century transport infrastructures, including city highways. It requires moving away from traditional car-centric transportation models to more sustainable, multimodal networks that can also improve the quality of public space (Degros and Bendiks, 2019). This paradigm shift is not merely about changing the physical infrastructure, but also involves rethinking urban planning, policymaking, and public attitudes toward urban transport and public space. By transforming transport infrastructures, cities can create more

livable, resilient, and equitable spaces, ensuring a healthier environment and better quality of life for present and future generations.

Urban scholars have utilized various methods to theorize urban transformations but often fail to address the myriad factors driving these changes. Urban development is influenced and constrained by complex networks consisting of diverse associations, leading to specific physical manifestations. We contend that actor-network theory (ANT) offers an essential framework for understanding the networks foundational to spatial and societal transformations. Through an ANT perspective, cities are continually shaped by evolving actor-networks, which emerge from the evolution of previous associations (Wissink, 2013) and elucidate the process of change and innovation via shifts in these networks (Olesen and Kroustrup, 2007). ANT advocates for a flat ontological approach to urban studies, highlighting the horizontal interconnections among various actor-networks. This challenges the dominant post-structuralist trends in urban planning (Fariás and Bender, 2010; Müller and Schurr, 2016), allowing us to discard any prior assumptions about the roles of specific transport infrastructures in our cities. By focusing on the situated and relational aspects of

actor-networks that underlie infrastructure projects, an ANT approach is pivotal for comprehending their inception and evolution. Thus, using a relational lens, ANT offers a unique perspective on spatial analysis in urban planning (Wang and Yau, 2018).

Although scholars recognize a gap in the literature and the necessity for more in-depth research on the subject, ANT has not been thoroughly used as a framework to analyze the theoretical and practical implications of urban infrastructure transformation projects. In the 21st century, the field of urban planning seldom leverages ANT to tackle climate change challenges, despite calls for its use to achieve a ‘radical democratic inclusiveness of the nonhuman’ for a more holistic examination of ecological issues (Hetherington, 2019). Furthermore, the need for deep engagement with sociology literature to fully comprehend ANT has been highlighted (Irish and Romkey, 2021).

Taking these considerations into account, the central question guiding this study is: How can ANT be applied to improve our understanding of contemporary urban transitions concerning sustainable transport transformations? Consequently, this paper aims to: (1) investigate the motivations and rationales behind the transformation processes of road infrastructure related to transport; (2) analyze the complex roles and relationships of various actors, both human and nonhuman, within these processes; and (3) offer insights into how municipalities can promote sustainable transformation of transport infrastructure using an ANT perspective.

We therefore use ANT to examine the formation and stabilization of actor-networks, assigning specific roles and importance to the various actors involved in the restoration process of the Catharijnesingel canal in Utrecht, the Netherlands. Understanding the roles of these actors is crucial, as they influence the negotiation processes among different stakeholders, guiding the selection of certain transformation strategies while excluding others. This includes, for instance, exploring how the municipal government of Utrecht interacts with various local stakeholders by centering discussions around a shared and desirable vision for the city’s future. To achieve this research objective, we use qualitative methods, such as document analysis, interviews, and on-site fieldwork, to uncover the intricate interplay of diverse actors, objects, and rationales.

The structure of this paper is outlined as follows: First, we introduce ANT scholarship and identify a gap in the literature concerning its application to urban infrastructure transformation. Subsequently, in the methodology section, we discuss the research methodology used and introduce the restoration of Catharijnesingel as a valuable case study that will be referenced throughout the remainder of this paper. In the Findings section, we elucidate the results obtained through an ANT lens. Following this, in the Discussion section, we theorize transformation mechanisms in relation to various transformation paradigms within the ANT framework and anchor some actions in the four moments of Translation developed by Callon (1984).

Finally, the Conclusion section summarizes the study’s contributions, discusses its limitations, and suggests areas for future research.

2. Literature review

2.1 Actor-network theory

ANT originated in science and technology studies (STS) in the 1980s and 1990s around pioneering sociologists Bruno Latour, Michel Callon, and John Law (Callon, 1984; Latour, 1987, 1988, 1999; Law, 1992, 1999). ANT is one of the most widely applied conceptual framework in contemporary social science for exploring sociotechnical processes (Fariás and Bender, 2010). It has been applied across various fields, including health, crime prevention, consumer research, urban studies, and management studies (Demant and Ravn, 2020). For example, ANT has been utilized in geography to explore how networks shape space from a distance, challenging the traditional nature/society dualism (Müller and Schurr, 2016). It has also been utilized to explore the connections between humans and animals (Wang and Yau, 2018). Typically, ANT uses qualitative data, mainly through ethnographic observations and document analysis. ANT boasts a comprehensive history of case studies that have introduced new concepts, providing a valuable framework for subsequent empirical research (Müller and Schurr, 2016).

ANT poses the main question: ‘How do things, people, and ideas become connected and assembled in larger units?’ (Czarniawska, 2017). Unlike conventional methods, ANT prioritizes circulations and flows over hierarchies and categories (Bosco, 2006). It underscores the concept of emergence, highlighting that the whole is greater than the sum of its parts (Müller and Schurr, 2016). Murdoch (1997) proposed that ANT provides insight into the interconnectedness of actions with materials, extending across time and space. This approach transcends dualistic frameworks commonly found in different contexts, such as local/global or micro/macro, where these terms hold significance only in relation to each other. Instead, ANT embraces a relational perspective of the world, in which action arises from the connection of initially separated elements. It adopts a topological perspective of space, where distance determines the strength of a relationship (Müller and Schurr, 2016). The theory encompasses both centralized actors and decentralized networks, emphasizing the significance of proximity within networks of space and time (Murdoch, 1998). Geographical ‘proximity’ and ‘distance’ are considered less relevant from an ANT perspective, with emphasis placed on proximity within networks (Murdoch, 1998).

As a result, ANT offers a more nuanced understanding of reality, acknowledging the intricate dynamics that shape social, technological, and environmental phenomena. The city is often seen as a dynamic and constantly evolving combination of human and nonhuman entities that form stable networks and assemblages with each other (Fariás and Bender, 2010). Urban developments encompass both material and cultural aspects, representing a dynamic interplay between nature and human intervention. This process involves the transformation of raw materials into infrastructure, buildings, and

artifacts, shaping the urban landscape. It is a complex phenomenon intertwined with diverse actors, including both human and nonhuman elements, and network dimensions such as material, political, ecological, economic, legal, discursive, and technical aspects.

2.1.1 Moving from agency-structure to actor-network

The structural/agency divide in sociology concerns the extent in which human behavior is determined by social structures (social class, religion, gender, ethnicity, customs, etc.) versus individual agency. Marxism has had a significant impact on urban history, leading urban scholars to distinguish between elements that require explanation and those that provide it (De Munck, 2016). This approach views social, economic, and ecological factors as causal determinants that shape urban development. In contrast, ANT is known for rejecting the distinction between the subject of explanation and the explanation itself, as well as between what is apparent on the surface and what lies hidden beneath. Bruno Latour (2005) argues that the concept of ‘social structures’ does not hold explanatory value and should instead be analyzed and explained, rather than used as an explanation. He claims that there isn’t a hidden reality that exists ‘behind’ or ‘underneath’ objects or events (De Munck, 2016). Instead, Latour presents a unique perspective that goes beyond the binary of technological determinism (realism) and social constructivism (idealism). He argues that entities, whether objects, humans, or ideas, derive their meaning and significance from the networks of relationships they are part of.

Within the framework of ANT, the idea of social structures is therefore substituted with networks, which are seen as concrete links and relationships between entities. In Latour’s framework, the more associations a thing has, the more ‘real’ it becomes (De Munck, 2016). This view emphasizes the agency and significance that entities gain through their alliances with others, shaping the world in a complex interplay between human and nonhuman actors (Ritzer, 2005). Rather than simplifying urban transformations as solely driven by technology or social constructs, ANT emphasizes its multifaceted nature and succeeds therefore in establishing a more nuanced interrelationship between urban transport infrastructure and society (Irish and Romkey, 2021).

2.1.2 Four moments of translation

Translation is central to ANT’s approach of ‘ordering struggles’ in a relational and distributed manner among actors (Ritzer, 2005). Translation, which involves transfer with deformation, serves as both a process and an outcome, understood in terms of the translator, the translated, and the translation medium (Ritzer, 2005). Actors are shaped by the relational network in which they are embedded, acquiring their characteristics through their relationships with other actors in the network (Latour, 2005). As networks ‘translate’, they redefine the roles of actors, influencing both societal and natural realms. This dynamic process of ‘displacement’, both social and physical, ‘simplifies’ entities while retaining their differences, converting them into ‘inscriptions’ or ‘immutable mobiles’ (Ritzer, 2005).

Operationally, translation unfolds through four distinct ‘moments’ or phases: *problematization*, *interessement*, *enrolment*, and *mobilization* (Callon, 1984). *Problematization* initiates the process, with an actor defining a problem and proposing themselves as key to its resolution, thereby outlining potential roles for others in the network. *Interessement* follows, where the actor seeks to secure the commitment of others to these roles, solidifying the network’s structure. *Enrolment* is the adoption and performance of these roles by the actors, operationalizing the network. Finally, *mobilization* is where the network, now active and coordinated, works to achieve its objectives, often represented by spokespeople who ensure the goals are met. These phases collectively illustrate the dynamic process of building and stabilizing actor-networks through the translation of actants (Burga and Rezanian, 2017; Pérez *et al.*, 2020).

In the domain of urban development, translation occurs as various actors consistently engage in negotiations and adjustments concerning the social and technical aspects of a specific context. These actors include both humans and nonhumans, and they are considered equal under the principle of symmetry, each contributing to the transformation process (Mol and Law, 1994). Moreover, they interact with each other in a reciprocal manner, where nonhumans influence humans just as much as humans influence nonhumans (Aka, 2019; Callon, 1984). Actors are shaped by the relational network in which they are embedded, acquiring their characteristics through their relationships with other actors in the network (Latour, 2005).

2.1.3 Suitability for this study

The principles of ANT are exemplified in the Catharijnesingel restoration in Utrecht, where the transformation of infrastructure is seen as an actor-network involving interactions among human and nonhuman entities across various spatial and temporal scales. This approach views infrastructure and society as inseparable, considering the restoration effort as a network of interconnections and exchanges that collectively shape the urban landscape. This process is characterized by the emergence of new networks and unforeseen connections among a diverse range of actors, often leading to controversies (Callon, 1984). From an ANT perspective, urban planning extends beyond the city government’s efforts and involves a complex network of various actors, including cyclists, canals, CO₂ molecules, former city walls, shopping malls, and more. These entities actively influence and are influenced by others within the actor-network, contributing to collective action. Consequently, no actor, whether human or nonhuman, operates in isolation and is worthy of further investigation.

3. Methodology

3.1 Grounded theory

We adopted a grounded theory method to analyze the restoration process of the Catharijnesingel canal in Utrecht as a representative case evolving from a canal in the 1930s to a city highway in the 1970s and back to a canal in the 2020s (see Figure 1). We used a single-case study approach as it offers deep insight into contextual relationships for theorization (Yin, 2003). Single-case studies with



Figure 1. Evolution of Catharijnesingel. Top photo: between 1930 and 1935 © Het Utrechts Archief (Catalogue Number 816409), middle photo: in 1973 © Het Utrechts Archief (Catalogue Number 801772), bottom photo: in 2021 © Het Utrechts Archief (Catalogue Number 900139). All photos CC BY 4.0

a broad research focus have also been used in other ANT research (Burga and Rezania, 2017; Callon, 1984; Sage *et al.*, 2011).

3.2 Case background

The Catharijnesingel is a water canal in Utrecht, the Netherlands. It forms the western segment of the Stadsbuitengracht, a ring canal

encircling the city's historic center (see Figure 2). Originating from the 12th century, it was initially constructed as part of the city's fortifications. In the 1960s, German traffic engineer Max Feuchtinger devised a plan to enhance car accessibility, proposing a 12-lane ring road over the canal (Boffey, 2020). However, due to substantial local resistance, only the northwestern and western parts of the Stadsbuitengracht were converted into a city highway and parking area. In 2002, Utrecht's residents voted in a referendum on the Utrecht Station Area Plan, which included the canal's restoration. This redevelopment project under the moniker CU2030 (2024) encompasses the train station, a shopping mall, and a music hall. The Catharijnesingel's northern sections reopened in 2002, but the full restoration was not completed until 2020. The restoration project was honored with the European Public Space Prize in 2022. Today, the canal supports a 6 km navigable route around the city center, enhancing the surrounding public spaces with activities like boating, walking, lounging on the grass, deck sitting, picnicking, and shopping. Future plans include connecting the Catharijnesingel to the Leidsche Rijn canal in the west, further reinstating water links (CU2030, 2024).

3.3 Data collection

We conducted ten exploratory semi-structured interviews during July 2023 and March 2024. We selected various field experts that were directly or indirectly involved in the restoration of Catharijnesingel. The interviewees included three professionals (urban planner, policy planner, mobility advisor) from the local municipality, a historian at the local history museum, a landscape architect doing the restoration design, a jury member for the European Prize for Urban Design, a Dutch bicycle activist, an assistant professor at the University of Amsterdam, and an artist/filmmaker. The interviews were conducted and transcribed in English, with intentionally open-ended questions to allow respondents to freely present their ideas and perceptions. Exemplary questions sought respondents' perspectives on the historical continuity related to the recent restoration of Catharijnesingel and strategies for addressing the diverse interests of multiple stakeholders. The durations of the interviews ranged from 30 min to 2 h, with the majority lasting approximately 1 h (see Table 1). These interviews generated more than 10 h of verbal discussions and produced over 40 pages of recorded transcripts. All transcripts were subsequently reviewed by the participants to verify their accuracy. Data collection and analysis were done in parallel and interviews were stopped when additional collected data did not reveal additional information, and no new theoretical insights were generated (Hennink *et al.*, 2017).

3.4 Data analysis

After transcribing and reviewing the interview material, we applied codes to the raw data. We created a preliminary codebook by selecting a subset of instances to define broad themes for analysis. Each instance was systematically coded according to its relevant transformation mechanism, and we identified the principal actor associated with each instance, coding them as human, nonhuman, or hybrid. Throughout this iterative process, new transformation mechanisms emerged and were incorporated into

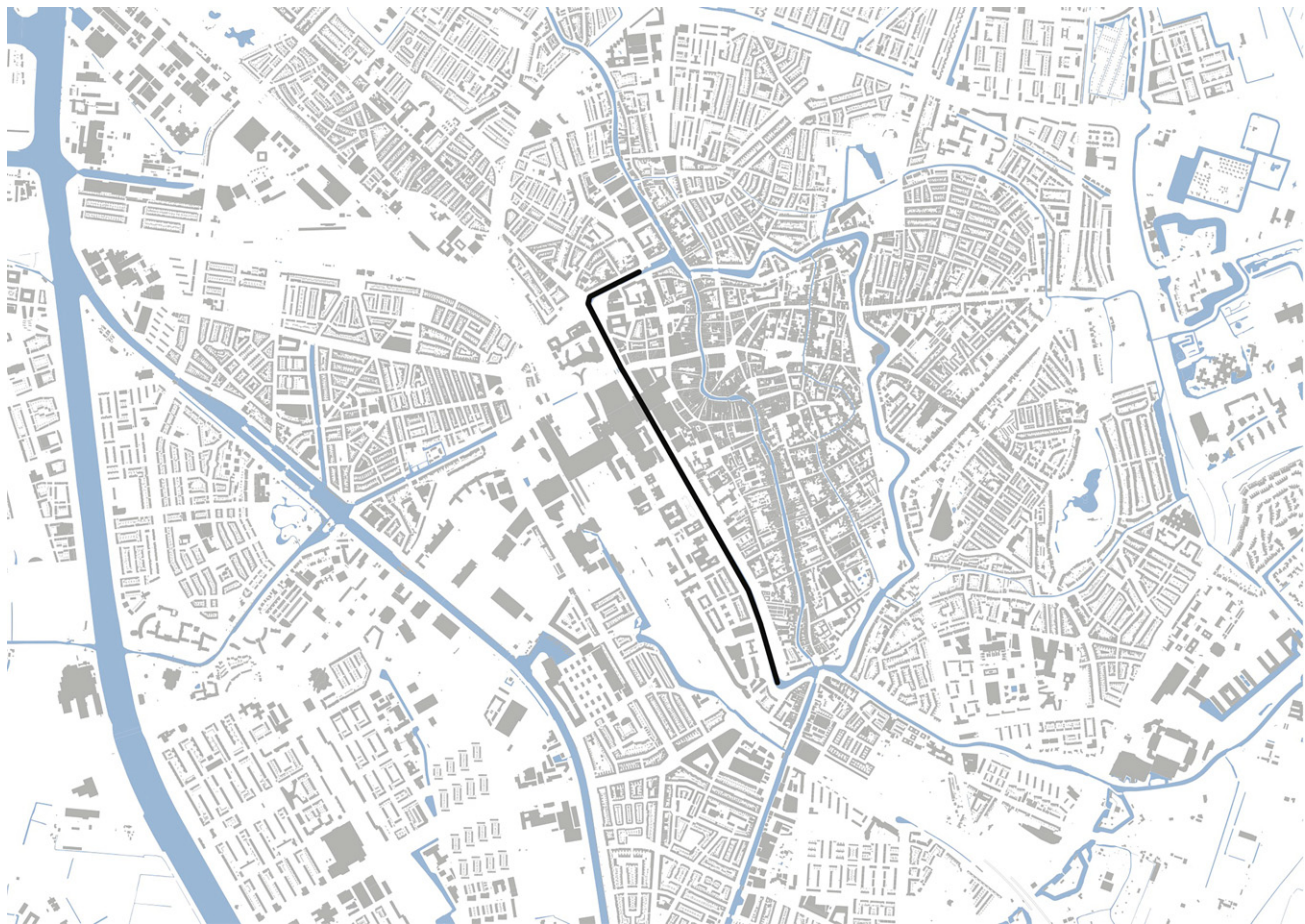


Figure 2. Utrecht with canal system in blue and Catharijnesingel restoration stretch in dark black

Table 1. Interview participants

#	Stakeholder	Duration
1	Curator of Urban History at Centraal Museum in Utrecht	2 h
2	Landscape Architect in charge of Catharijnesingel-South	1 h
3	Jury member in the European Prize for Urban Public Space 2022	1 h
4	Urban Planner at the City of Utrecht	1 h
5	Policy Advisor at the City of Utrecht	1 h
6	Mobility Advisor at the City of Utrecht	1 h
7	Book author and activist for cycling in the Netherlands	1 h
8	Former Deputy Mayor at the City of Utrecht	1 h
9	Assistant Professor at the University of Amsterdam	30 min
10	Artist and Filmmaker	1 h

the codebook. This methodical coding process facilitated an exploration of actants, drawing on indicators for the application of ANT, and enabled an in-depth analysis of the actors’ interactions within the network. As the analysis advanced and new themes emerged, we identified additional actors and examined their influence

on and interactions with the actor-network, revealing various transformation paradigms. The findings will be discussed in the remainder of this article.

4. Findings

During the analysis stage, ANT functioned as both a theoretical lens and a research methodology, providing insight into several transformation mechanisms of transport infrastructure at the municipal level. By prioritizing the ‘how’ over the ‘why’ in examining the formation of actor-networks (Callon, 1984; Tomazos and Murdy, 2023), ANT presented a pragmatic approach to case study analysis. To understand the restoration process of the Catharijnesingel canal as a phenomenon ‘in the making’ (Latour, 1987), we must ‘follow the actors’ (Latour, 1993) who have contributed to its existence, success, or failure by tracing their actions. We thusly identified several principal actors ($n = 16$) related to the theme of sustainable transport that played a role in the restoration of the Catharijnesingel restoration (see Table 2). These actors or ‘actants’ have the ability to act or influence outcomes within a network. According to the principle of symmetry, those actors can be both human and nonhuman. In addition, we identify various ‘hybrid’ actors in this study, which embody both human and nonhuman components.

Table 2. Instances extracted from interviews related to sustainable transport, categorized by principal actor, actor dimension, transformation paradigm, and transformation mechanism

Serial number	Instance	Principal actor	Actor dimension	Transformation paradigm	Transformation mechanism
1	Business owners are anxious about losing parking spaces for their clients.	Business owners	Human	Economic	Accessibility
2	The shopping mall continues to provide good access for car traffic.	Shopping mall	Hybrid	Economic	—
3	A new pedestrian bridge spans over the railway to reconnect the neighborhood.	Pedestrians	Human	Spatial	—
4	The train station has been made accessible independently from the shopping mall.	Train station	Hybrid	Spatial	—
5	Car traffic ‘evaporates’ due to changes in people’s behaviors.	Car drivers	Human	Cultural	Modal shift
6	Bicycle garages are becoming too small due to the increasing number of bicycles.	Cyclists	Human	Cultural	—
7	A large bike garage provides convenient access to the train station for cyclists.	Parking	Nonhuman	Mobile	—
8	New housing developments provide only 0.3 parking spaces per household.	Parking	Nonhuman	Mobile	—
9	Discussions are underway regarding the potential adaptation of the canal as a transport infrastructure for cyclists.	Cyclists	Human	Political	—
10	Providing incentives for soft mobility and offering attractive alternatives to car traffic encourage behavioral changes.	City government	Hybrid	Political	—
11	Every year, over 50 car parking lots are converted for uses like cycling facilities, green spaces, or café outdoor seating.	Parking	Nonhuman	Spatial	—
12	The available traffic space is redistributed and requalified, with a priority given to soft mobility.	Road	Nonhuman	Spatial	—
13	The shift toward cycling indirectly benefits car traffic flows, resulting in lower congestion levels.	Cyclists	Human	Mobile	Network efficiency
14	As cities become denser, they require more efficient transportation systems to meet increasing demands.	Road	Nonhuman	Mobile	—
15	Plans are in place to reestablish the water link between the Leidsche Rijn river and the Catharijnesingel.	Waterway	Nonhuman	Mobile	—
16	The highway was perceived as a barrier that contributes to the fragmentation of urban spaces.	Road	Nonhuman	Spatial	—
17	Walking and driving routes had to be redefined due to the restoration of the Catharijnesingel.	Waterway	Nonhuman	Spatial	—
18	Enhanced livability and reduced stress levels among residents are attributable to decreased background noise from car traffic.	Noise	Nonhuman	Ecological	Reducing car traffic
19	The implementation of car-free zones has enhanced the shopping experience.	Business owners	Human	Economic	—
20	Soft modes of transportation are cheaper and more efficient for reaching the city center compared to car traffic.	Car drivers	Human	Economic	—
21	Bikes can be parked without any charge for the first 24 h, in contrast to the expensive parking fees for cars.	Parking	Nonhuman	Economic	—
22	Cheap park-and-ride facilities located on the city’s outskirts are designed to discourage cars from entering the city center.	Parking	Nonhuman	Economic	—
23	Car drivers are redirected around the center to avoid thoroughfare traffic.	Car drivers	Human	Mobile	—
24	A large parking lot containing 500 spaces is scheduled to be demolished in 2028 as an attempt to further discourage car use.	Parking	Nonhuman	Mobile	—

(continued on next page)

Table 2. Continued

Serial number	Instance	Principal actor	Actor dimension	Transformation paradigm	Transformation mechanism
25	The tragic death of a child in a car traffic accident has sparked widespread protests against urban vehicular use.	Protestors	Human	Political	—
26	Pollution levels have decreased following compliance with EU air quality regulations.	Air	Nonhuman	Political	—
27	Reducing available space for cars and making driving less efficient aims to counteract the 'induced demand' effect.	Road	Nonhuman	Spatial	—
28	Car lanes were reduced from six to two following the restoration of the Catharijnesingel.	Road	Nonhuman	Spatial	—
29	The canal within the city is used to transport beer and other items to restaurants by electric boats.	Boat drivers	Human	Ecological	Urban logistics
30	Traffic flows have been redesigned to enable dedicated underground access for equipment delivery to the music hall.	Music hall	Hybrid	Mobile	—
31	Plans are underway to utilize the canal for logistics to prevent large trucks from entering the city center.	Delivery drivers	Human	Spatial	—

4.1 Human actors

Human actors in ANT are individuals or groups who actively contribute to the actor-network. In this study of the Catharijnesingel restoration, we identified seven human actors related to the theme of sustainable transport at the municipal level: car drivers, cyclists, pedestrians, business owners, protestors, boat drivers, and delivery drivers.

We identified car drivers as a significant human actor within the Catharijnesingel restoration network. Car traffic 'evaporates' as a result of changes in people's behavior, drawing a parallel with water (Instance 5). This comparison implies that traffic, much like water, doesn't simply redistribute to neighboring streets when a major route is closed; rather, it appears to evaporate and vanish. In reality, part of the car drivers transition to softer modes of transportation, which are frequently more cost-effective and efficient for accessing the city center than vehicular traffic (Instance 20):

No, it's really surprising, and we've wondered about the same things - like, where have all the cars gone? I think it's because people are choosing different options. For example, if someone wants to visit the city, taking the train is much easier. (Interview #5)

The restoration of the Catharijnesingel has led to a deliberate redirection of car drivers to circumvent the city center (Instance 23). The previous inner-city loop has been minimized to a shorter route, with the emphasis on using highways around Utrecht. This change has effectively eliminated the need for an inner-city tour, though it remains possible for those who do not mind delays.

Cyclists are considered another crucial human actor in the Catharijnesingel restoration network. Bicycles have emerged as a strong alternative to cars. Some bicycle garages are becoming too small to accommodate the growing number of bicycles in the city

(Instance 6). Furthermore, discussions are underway about utilizing the restored Catharijnesingel as a transportation route for cyclists (Instance 9). Moreover, a shift toward cycling not only promotes a healthier and more sustainable mode of transport, but also indirectly benefits car traffic. As more people opt for bicycles, the number of car drivers decreases, leading to less congested roads for those who continue to drive (Instance 13). This transition supports the broader goal of creating more efficient and environment-friendly urban environments.

Pedestrians are becoming increasingly relevant within the actor-network. Presently, there is a prioritization of pedestrian zones and car-free shopping streets. The redevelopment of the station area and the restoration of the Catharijnesingel led to the installation of a new pedestrian bridge (Instance 3). This bridge, spanning the railways on the south side-of the train station, connects the old city with new urban developments on the station's western side. Funded by Raaberbahn, the bridge will provide direct access to the train platforms in the future.

Business owners constitute another human actor within the Catharijnesingel restoration network. They are eager to preserve parking spaces to ensure accessibility for their customers (Instance 1).

It's a complex issue because the business owners are deeply concerned about the potential loss of parking spaces and similar matters. Despite the government's success in eradicating car traffic along the old canal, attaining this objective remains challenging. (Interview #1)

However, the establishment of car-free zones has improved the shopping environment, thus positively impacting business owners (Instance 19). Specific sections within the city have been allocated as car-free zones, allowing only essential logistics traffic between 7 a.m. and 11 a.m. Outside of these hours, the area is exclusively reserved

for pedestrians. These enhancements not only increase the city's appeal to residents and tourists, but also have the potential to boost local commerce by creating a more enjoyable and accessible shopping experience.

Protestors gained relevance with the tragic event where a newspaper editor's daughter died in a traffic accident (Instance 25). This spurred a nationwide movement under the banner 'Stop de kindermoord' (Eng. stop the child murder). The movement was not solely a response to traffic victims; it led to the unexpected formation of a coalition that included preservationists, environmentalists, anarchists, cyclists, and public health advocates. Despite their diverse reasons for involvement, they joined forces with the shared aim of advocating for livable cities. Their activities extended beyond mere protest, encompassing the organization and *mobilization* to support political candidates who rejected car-focused urban design. Consequently, the protesters emerged as a significant actor in creating the actor-network of the Catharijnesingel restoration.

Boat drivers are human actors that are using the canal for logistic or touristic purposes. Some of them transport beer and various other items to restaurants using electric boats (Instance 29). The city government is currently exploring the potential expansion of the canal's use for logistics and waste collection. However, in some parts of the Catharijnesingel, boat passage of taller ships is no longer possible due to the limited clearance of the new bridges. This design choice avoided complications that higher bridges would have introduced. Also, safety concerns have emerged regarding conflicts between larger tour boats and swimmers using paddle boards. Tour boat operators have requested a minimum clearance of 20 m to ensure safe passage for everyone. Despite potential risks posed by boat traffic and uncertain water quality, the canal still attracts swimmers.

Delivery drivers emerge as human actors in supplying the city with logistical services, encompassing goods delivery and waste collection. As mentioned above, plans are underway to introduce water-based solutions for delivery drivers to avoid the necessity for large trucks to enter the city (Instance 31):

When I was *** [designation hidden], I initiated the "beer boat," enabling cafes to receive their supplies through the waterways. Currently, there are plans to extend this service to deliver goods to shops by water. The aim is to reduce the presence of large delivery vehicles in the city. (Interview #8)

4.2 Nonhuman actors

Nonhuman actors in ANT can include a wide range of entities, such as animals, objects, technologies, or even ideas. It challenges the traditional human-centric view of agency by acknowledging that nonhuman entities can also enact change. In the study of the Catharijnesingel restoration we identified five nonhuman actors related to the theme of sustainable transport at the

municipal level: the road, the parking, the waterway, air, and noise.

The road is the most significant nonhuman actor in the Catharijnesingel restoration network, serving as essential infrastructure. Traffic space is redistributed and requalified by dedicating infrastructure to active modes of transportation, such as walking and cycling (Instance 12). As urban centers become increasingly densely populated, there is an urgent need to reallocate traffic zones to optimize the effectiveness of transportation systems and accommodate rising traffic volumes (Instance 14). This strategy makes it possible to increase the density of the city centre without adding to car traffic. The diminishing availability of open areas underscores the importance of prioritizing spaces designated for transport over static uses. Moreover, the old highway that ran along the Catharijnesingel was seen as a barrier that exacerbated neighborhood fragmentation in Utrecht (Instance 16). Crossing from one side to the other without passing through Hoog Catharijne presented a considerable challenge. These barriers created by infrastructure hinders pedestrian flows, resulting in disconnected urban areas.

According to the 'induced demand' principle, providing space for cars inevitably leads to increased car traffic. Conversely, reducing space for cars and making driving less efficient aims to reverse the 'induced demand' effect (Instance 27). This change encourages people to alter their habits, which is a crucial aspect of the broader challenge cities worldwide face:

It's clear that we cannot simply transition to electric vehicles for the nearly one billion cars globally without addressing other issues related to quality of life and safety. By encouraging a shift in transportation modes through infrastructure design and space reallocation, we can diminish the dominance of car dependency. (Interview #7)

In the restoration of the Catharijnesingel, the number of car lanes was reduced from six to two (Instance 28). Furthermore, the two remaining car lanes will soon undergo another change, as barriers will be erected to halt through traffic. Within a few months, there will be no through traffic in the city, signaling a continuous progression of changes.

Car and bicycle parking plays a crucial role as nonhuman actors within the Catharijnesingel restoration network. A new bicycle garage offers convenient access to the train station for individuals arriving and departing by bicycle (Instance 7). This illustrates the capacity of infrastructural incentives to shape mobility behaviors. Another strategy for reducing car traffic involves limiting the provision of parking spaces to only 0.3 per household in new housing developments (Instance 8). Previously, there was one parking space per household. Today, some areas are even designed without car parkings, focusing instead on car-sharing options. Personal cars cannot be parked directly under homes, forcing residents to either pay for parking in a public car park or to utilize a large car park outside the city, then commute by bike or tram. By implementing such measures, 50 car parking lots can be further repurposed each year

for alternative uses, such as bike parking, green spaces, or outdoor seating for cafes (Instance 11).

We're adopting a new approach to travel in our city, aiming for fewer cars—ideally, none at all. Our plan focuses on stopping the increase of cars by not adding any more parking spaces. In fact, we're considering removing parking spots as a way to discourage car use. (Interview #5)

In the city of Utrecht, bicycles can be parked free of charge for the first 24 h, unlike the costly parking fees for cars (Instance 21). Additionally, the expense of car parking rises annually. The newly established park-and-ride facilities on the outskirts of Utrecht play a vital role in decreasing car traffic, as they actively discourage driving into the city center (Instance 22). These facilities offer economical car parking and convenient connections to public transport, including the tram service to the central train station.

I live in a suburb of Utrecht, and I have the choice to either drive to an expensive parking spot in the city or park my car on the outskirts and take the tram into the city for a small fee. Sometimes, the decision is based on cost. (Interview #5)

Because of these measures, old garages designated for car parking can be removed to further discourage car usage. By 2028, a significant parking lot in the center, accommodating 500 spaces, is scheduled for demolition (Instance 24).

The waterway serves as another nonhuman actor. As the restoration of the Catharijnesingel introduced yet another barrier, walking and driving routes had to be redefined (Instance 17). Moreover, there are plans to enable boat access to the city by reestablishing the water network (Instance 15). Historically, the canal served as the primary route for transporting goods into the city. However, this function diminished as the waterway's role was gradually replaced by the Merwede canal and later the Amsterdam-Rijn canal, ultimately leading to a complete loss of its original purpose. In the 1970s, with the construction of the motorway and the mall, the historical connection between the Leidsche Rijn river and the canal was obstructed. The initiative to reopen canals will not only create additional water surfaces, but also enable boat access to the city.

Air represents a nonhuman actor in the actor-network regarding pollution levels. In the restoration of the Catharijnesingel it was necessary to comply with binding EU air quality regulations (Instance 26). Following the implementation of air quality regulations in 2007/08, the city faced challenges with exceeding NO₂ limits, impacting the approval of new projects such as farms and roads. This situation, stemming from the implementation of these strict European regulations, has been met with mixed reactions; some view the binding adherence of the Netherlands to these regulations as a fortunate mistake, while others are frustrated by the restrictions this entails.

Noise can also be seen as a nonhuman actor that influences stress levels among residents due to background noise from car traffic

(Instance 18). Measures to enhance air quality and reduce noise pollution have notably improved livability and health benefits.

4.3 Hybrid actors

Hybrid actors in ANT are entities that are composed of both human and nonhuman elements. These hybrid actors illustrate the theory's focus on co-dependency and interconnectedness of various actors within a network. They demonstrate that networks are complex formations where humans and nonhumans mutually shape each other's influence and existence, blurring the lines between social and technical aspects. In this study of the Catharijnesingel restoration, we identified four hybrid actors related to the theme of sustainable transport at the municipal level: the city government, the music hall, the shopping mall, and the train station.

The city government is an important hybrid actor in the network of the Catharijnesingel restoration. From an ANT perspective, the city government is not simply an organization, but rather a complex network of people, policies, technologies, buildings, and other interconnected elements. The actions of the city government are not solely determined by human decision-making, but are also impacted by nonhuman factors such as legal frameworks, technological systems, and infrastructure. Human decisions are shaped by nonhuman constraints and opportunities, just as nonhuman elements are influenced and shaped by humans. The effectiveness and functioning of a city government depend on the interactions within this network.

In the case of the Catharijnesingel restoration, the Utrecht city government offered appealing alternatives to car mobility as part of the restoration project, aiming to encourage shifts in citizens' traffic behaviors (Instance 10). To effectively promote behaviour change, it is essential to enhance the appeal and convenience of walking, cycling, and public transport, ensuring seamless integration between various modes of transportation. The following statement showcases the city government's ability to utilize a comprehensive urban project that extends beyond the simple restoration of the Catharijnesingel. The interviews also underscored the vital role of the city government in building consensus on the necessity of restoring the Catharijnesingel and in maintaining a progressive administration capable of sustaining momentum over two decades.

Everything takes a long time in the Netherlands. I think it required considerable governmental courage and implicated significant costs. We needed a city government willing to say, "Let's do it." The referendum had to pass, and the funds had to be available, reflecting the consensus on its necessity. (...) And indeed, the political direction has remained unchanged for two decades, which is quite remarkable when you consider it. (Interview #4)

The music hall has been identified as another hybrid actor. TivoliVredenburg is a contemporary music hall that is part of the urban redevelopment scheme CU2030 (2024) and opened in 2014.

To facilitate the delivery of equipment by large trucks, traffic flows had to be redirected. The facility now features an underground access route, regulated by a traffic light to manage entry, representing a considerable investment to ensure smooth operations (Instance 30). New stairs in front of the music hall provide a space for people to sit and enjoy the evening sunshine, thereby offering an accessible, consumption-free open area for both residents and visitors.

With Tivoli-Vredenburg, the new music hall, the experience is vastly different from before when it was surrounded by highways; now, you can sit in front of it and enjoy a drink on a terrace. (Interview #1)

The shopping mall represents a hybrid actor in the studied actor-network. Hoog Catharijne is one of the largest shopping malls in the Netherlands, strategically situated between the train station and the music hall. It is spanning the restored Catharijnesingel that is visible through transparent sections of the mall's floor, integrating the historical presence of water into the modern shopping experience. Hoog Catharijne had been under construction since around 1965 and was considered outdated by the time it was completed. The comprehensive renovation of the shopping mall is a crucial element of the urban redevelopment initiative, CU2030 (2024), which aims to transform the entire station area. In this process, the shopping mall emerged as a significant hybrid actor, particularly in the restoration of the Catharijnesingel.

In the 1960s, the shopping mall provided direct access via a highway that crossed the Catharijnesingel. This facilitated the arrival of visitors from outside the city, who also shopped in the historic center, thus revitalizing it. At a time when many city centers were experiencing a decline in public presence and retail activity, Utrecht saw a beneficial influx associated with the mall. Today, Hoog Catharijne still maintains good connectivity for car traffic (Instance 2). However, fewer people are visiting the station area and the shopping mall by car, leading to a decline in demand for parking garage spaces. There are plans to repurpose the vacant car parking levels in the shopping mall into bicycle parking areas to adapt to changing mobility behaviors and to free up outdoor spaces from bicycles.

The train station is another hybrid actor in the Catharijnesingel restoration. Utrecht Central Station serves as the most important transit hub in the Netherlands, integrating three bicycle parking areas, two bus stations, two tram stops, and the railway station. There was a historical contractual agreement between the city and Klépierre, the owner of the shopping mall, to direct pedestrian flows to and from the train station through the shopping mall. The redevelopment of the entire station area has made it possible to provide new pathways for accessing the train station independently from the shopping mall (Instance 4). Now, individuals can entirely bypass the mall, thanks to a new staircase and elevators that lead directly to the central station's square. Despite these changes, many people still decide to walk through the mall.

5. Discussion

The findings presented in the previous section emphasize the variety of actor-networks that supported the successful restoration of the Catharijnesingel. By examining the restoration of the Catharijnesingel through an ANT lens, we have identified five transformation mechanisms: reducing car traffic, modal shift, network efficiency, accessibility, and urban logistics. We will further theorize these transformation mechanisms in relation to the following six underpinning transformation paradigms: economic, ecological, political, cultural, spatial, and mobile. Moreover, crucial moments of the Catharijnesingel restoration are anchored in the four principles of translation within the ANT framework, as developed by Callon (1984). This process, which is nonlinear and iterative, includes *problematization* (defining the problem), *interessement* (negotiating with actors to join the network), *enrolment* (establishing and interlinking terms and connections), and *mobilization* (where the actors implement the network's agenda).

5.1 Reducing car traffic

The restoration of the Catharijnesingel hinges predominantly on reducing car traffic, acting as a pivotal mechanism for transformation, which is sustained by economic, mobile, political, spatial, and ecological paradigms. Economically, there is a shift toward incentivizing alternative modes of transportation while imposing constraints on car parking within central zones. Notably, the establishment of car-free zones has proven advantageous for businesses, enriching the shopping experience for their clients. In terms of mobility, strategies involve rerouting car traffic away from the city center and reevaluating the classification of parking spaces. Political paradigms emphasize child safety and air quality regulations, making it a matter of public concern. Spatially, there's a notable reduction in the allocation of space for cars, aimed at counteracting the phenomenon of induced demand. Finally, stemming from an ecological paradigm, reducing car traffic is imperative in mitigating noise pollution, thereby positively impacting public health outcomes.

Examining the transformation mechanism of 'reducing car traffic' through an ANT lens, several moments of translation become apparent. The *problematization* of car traffic occurred when the daughter of a newspaper editor was killed in a traffic accident, prompting safety concerns for children in the Netherlands. Various actors were identified and their relationships established within the actor-network. Protesters played a crucial role in identifying and describing the car-centric urban model as the problem, as well as formulating a strategy against it (Sergeeva and Ninan, 2023). During this phase, protesters were willing to break away from conventional methods to dissociate from current practices to seek new coalitions. This principal actor outlined the responsibilities of various human and nonhuman actors in tackling the identified issue (Korah, 2020) and established an unexpected network of actors that would be able to speak on behalf of the issue.

In that process of *problematization*, the city highway marked the Obligatory Passage Point (OPP), signifying that actors within the network must fulfill or meet the objective of restoring the Catharijnesingel to address the network's overarching challenge of safe spaces for children (Tomazos and Murdy, 2023). Actants frequently strive to position themselves as 'obligatory passage points', becoming essential elements for the sustained success of the network (Madden, 2010). Bruno Latour underscores the importance for actors to recruit allies and isolate opponents in the battle for control over obligatory passage points, which are crucial for maintaining the stability of a network of actors (Latour, 2005; Ritzer, 2005).

5.2 Modal shift

Numerous modal shifts characterize the restoration of the Catharijnesingel, propelled by cultural, mobile, political, and spatial paradigms. Cultural paradigms trigger behavioral changes that become apparent in bike garages reaching their capacity limit and the intriguing phenomenon of 'evaporating' car traffic. Mobile paradigms drive the establishment of the world's largest garage adjacent to the train station and pioneering residential projects devoid of personal car parking spaces. Political paradigms incentivize appealing alternatives to car usage while sparking debates regarding the potential use of the canal for transportation. Finally, spatial paradigms facilitate modal shifts through the redistribution and repurposing of traffic areas, prioritizing public spaces and promoting sustainable modes of transportation.

In ANT terms, *interessement* for modal shifts began with the city government providing incentives for soft mobility as attractive alternatives to car traffic to encourage behavioral changes. During the *interessement* phase, cyclists, as key actors, strive to solidify the roles and responsibilities of other participants (such as car drivers and pedestrians) as initially proposed (Callon, 1984). The city government seeks allies (such as the train station and shopping mall) and aims to link them to the project for their mutual benefit. This phase is marked by negotiations, strategies, and tactics aimed at aligning the interests of potentially divergent entities with the network's objectives (Ninan *et al.*, 2019). The goal is to lock actors into the roles and pathways outlined during *problematization* (Tomazos and Murdy, 2023). Consequently, the project becomes operational, and the relationships among actors become dynamic.

The moment of *enrolment* was formally initiated with the opening of a large bicycle garage in the station area, providing convenient access to the train station for cyclists. This phase involves cyclists actively adopting and performing the roles and functions defined during the *problematization* phase. This crucial phase marks the transition from the theoretical framework established in the *problematization* phase to its materialization through concrete actions and commitments (Tomazos and Murdy, 2023). In this process, actors effectively translate relationships using power, often

referred to as 'trials of strength' (Sage, Dainty and Brookes, 2011). The bicycle garage is experiencing a lack of space due to its growing popularity, indicating the onset of a new phase of *problematization*.

5.3 Network efficiency

Network efficiency is a pivotal transformation mechanism in the actor-network of the Catharijnesingel restoration, driven by both mobile and spatial paradigms. Mobile paradigms entail the need for enhanced transportation systems as urban density increases, the restoration of water connections, and the acknowledgment that promoting cycling also indirectly benefits traffic flow for cars. Spatial paradigms stem from the barrier effect of infrastructures, leading to urban fragmentation, and from the reconfiguration of traffic patterns following infrastructure changes.

The *mobilization* phase of translation corresponded to the redesign of walking and driving routes following the restoration of the Catharijnesingel. *Mobilization* occurs when actors are enlisted to further stabilize the network, such as the waterway or adjacent green spaces. Consequently, it now appears feasible to adapt the waterway as an important transport infrastructure by reestablishing the water link between the Catharijnesingel and the Leidsche Rijn. The *mobilization* phase also signifies the phase where actors can utilize occurrences within a project as universal examples, thus generalizing specific relationships among actors for future projects (Callon, 1984). In this vein, the restoration of Catharijnesingel has been hailed as a best-practice example of urban renovation, with growing interest from experts worldwide.

5.4 Accessibility

Accessibility serves as a pivotal transformational mechanism, encompassing both economic and spatial paradigms. Economically, both business owners and shopping malls rely heavily on customers arriving by car. Moreover, spatial connections play a crucial role in optimizing accessibility as a transformative mechanism.

A significant step in *mobilization* took place with the establishment of a dedicated access path to the train station, independent from the shopping mall. Originally, the agreement between the municipal government and Klépierre intended to funnel all foot traffic through the mall. However, this 'black-box' was reopened with the introduction of the new route, thereby improving pedestrian access to the train station. Furthermore, a new footbridge now extends over the railway lines, offering the promise of direct platform access in the future. This development in 'black-boxing' accessibility indicates a shift where pedestrian movements, crucial practices within the network, are increasingly becoming institutionalized processes (Tomazos and Murdy, 2023).

5.5 Urban logistics

Urban logistics stands out as the final identified transformation mechanism within the actor-network of the Catharijnesingel

restoration. This mechanism encompasses ecological, spatial, and mobile paradigms. Adhering to these paradigms, electric boats have emerged as viable alternatives to space-consuming trucks in urban logistics. Furthermore, highly specialized programs including the music hall necessitate dedicated delivery access to meet their unique local demands of the community (Ninan *et al.*, 2024).

With the complete reopening of the Catharijnesingel, there are also new phases of *interessement* emerging in relation to urban logistics. Discussions are going on to use the canal as a means of transport for logistical purposes, especially for last-mile deliveries. Meanwhile, conflicts among various users of the waterway underscore the potential for additional phases of *problematization*.

6. Conclusion

In this study, we have advanced the understanding of ANT within the context of transport infrastructure transformation. Our investigation revealed how ANT can elucidate the roles and interactions of diverse actors, both human and nonhuman, in shaping sustainable transport systems at the municipal level. By identifying and analyzing principal actors, mechanisms of transformation, and underlying paradigms, our research contributes to a more nuanced comprehension of the complexities involved in urban transitions. ANT provides a robust framework for revealing and understanding how various actor-networks in transport infrastructure, operating under often divergent paradigms and interests, affect urban transformation processes and eventually their success or failure. Moreover, ANT suggests that what is commonly assumed to be given, such as the growing emphasis on soft mobility, is actually a temporary settlement negotiated among different actors.

The limitations of single case studies in terms of generalizability are acknowledged. However, the extensive information collected and analyzed during the examination of the Catharijnesingel restoration project has uncovered discernible actor-network patterns. The inductive analysis process of ANT facilitates the transition from simple relationships to complex networks that are characterized by a convergence of diverse forces and interests. This not only enriches our understanding of sustainable urban development, but also provides valuable insights for future research in this area. It is imperative to conduct additional research to apply the ANT approach to similar infrastructure transformation projects in different contexts. This will enable the generalization of findings and contribute to the development of a comprehensive theory of sustainable transport infrastructure transformation. Future research should focus on applying ANT to a variety of transport infrastructure projects across different geographic, socioeconomic, and cultural contexts to validate and generalize findings from single case studies like the Catharijnesingel restoration project. In addition, extending ANT to other urban infrastructure themes (society and representation, space and development, innovation and preservation, health and environment) and examining the intersections between them can provide a holistic understanding of urban transformation

processes in general and sustainable transport infrastructure transformation in particular.

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