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Systematic Review

A Systematic Review on Complexity in Collaborative Infrastructure Projects

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Abstract

Projects in the infrastructure sector are becoming increasingly interdependent and complex, and how to deal with that complexity is something to pay close attention to in the process of developing a sustainable society. This article sets out to provide an overview of how complexity is dealt with in real projects and thus asks the question of how complexity is considered in scientific literature, based on empirical studies about collaboration in infrastructure projects. Consequently, this article presents a structured literature review using PRISMA. Three scientific libraries were used: Web of Science (for 1 January 2000–31 December 2023), Scopus (for 2000–2026), and OpenAlex (for 2024–2026). The search query included complexity, collaboration, infrastructure, project management, and case study, as well as synonyms. A total of 43 articles were included in the final sample for the review. Interestingly, the analysis of the sample reveals that the initial expectations were not met, so instead of creating a comprehensive overview of the methods used to deal with complexity, a different discovery is made instead: complexity is often mentioned, but is hardly defined, barely operationalized, and not understood.

Keywords: complexity; project management; systematic literature review (SLR); collaboration; infrastructure

1. Introduction

Given the energy transition towards a sustainable society, infrastructures are increasingly interdependent on other infrastructure (c.f., [1]). In turn, society is dependent on its infrastructure to function properly, ensure societal well-being, secure the economy, and keep its inhabitants healthy and its assets safe. This is reflected in the United Nations (UN) Sustainable Development Goals (SDGs) [2], namely the strive towards clean water and sanitation (goal 6), affordable and clean energy (goal 7), decent work and economic growth (goal 8), industry, innovation, and infrastructure (goal 9), and, lastly, sustainable cities and communities (goal 11). The goal of sustainable societies cannot be achieved without well-functioning infrastructure. To reach the SDGs, current infrastructure needs to adapt and evolve. To do so, it is vital to understand (project) complexity and consider the challenges for project management and/or the management of infrastructure projects c.f., [3–5].

The interconnectedness of infrastructure is like a system-of-systems where each infrastructure system provides its own service but must be connected to other infrastructure systems in the process [6] (p. 1) (c.f., [7]). A well-known example of interdependency is the electrification of cars (c.f., [8,9]). "An interdependency is a bidirectional relationship

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between infrastructures through which the state of each infrastructure is influenced by or correlated to the state of the other" [6] (p. 2), or, to phrase it differently, interdependency is "[...] establishing connections between infrastructures where the condition of one is influenced by the other and vice-versa" [10] (p. 175). The element of interdependency means that infrastructure is reliant on other infrastructure to function properly. As an example, most infrastructure is dependent on electricity: "[...] telecommunication networks require electricity, transportation networks often use sophisticated, computerized control and information systems, the generation of electricity requires fuels, and so forth" [6] (p. 1). Dependencies between infrastructures make it so that if, e.g., the electricity infrastructure fails, then other infrastructure will fail to function properly as well (c.f., [6,10,11]). The opposite also holds true: the electricity grid depends on, e.g., data for its management for maintenance and repairs. In, e.g., the design processes and development phases of infrastructure systems, this interconnectedness adds to the complexity of decision-making [6] (p. 1). Having to consider the interconnectedness of infrastructure when planning and designing for an infrastructure project complicates the project. The project requires a shift in focus from one infrastructure's design to the design of interconnected infrastructure. An infrastructure is no longer 'isolated' on its own and is left more vulnerable to disturbances from other interconnected infrastructure. In that connectedness between infrastructure, both physically and—perhaps more importantly—collaboratively lay vulnerabilities that are inconceivable without understanding the complexity of the project. Since infrastructures have become increasingly interdependent (c.f., [12–17]), understanding the implications of that interdependence in collaborative infrastructure projects requires attention.

The current literature on, e.g., critical infrastructure protection mainly focuses on the consequences of disturbances in infrastructure networks and the mitigation of threats and risks leading to disturbances (c.f., [18–20]). In other words, the focus is mainly on the vulnerabilities in infrastructure assets themselves and their connections to other infrastructures, as well as on the prevention of failure and its cascading potential. There is less focus on the 'hidden' vulnerabilities that come from the collaborative process in which the assets are built. "The notion of critical infrastructure is counterfactual, because we do not know in advance, due to systems evolution, complexity and shifting intentions and actions of relevant actors, where failure will occur and what impact this will have" [21] (p. 419) (for clarity, the term 'actor' will be used interchangeably with the term 'stakeholder' throughout this article). This means that critical infrastructure cannot be constructed and interdependent with other infrastructures while also preventing all potential interruptions and their cascading effects on the critical infrastructure in an unpredictable environment. Arguably, the same can be said for any infrastructure that is interdependent with other infrastructures, regardless of whether it is critical infrastructure or not. In that regard, critical infrastructure is no different from other infrastructure. Clarification is, however, in order; this article includes all infrastructures in general and does not discriminate between critical infrastructure and other infrastructures. If all of the information about (physical) interdependent assets is known, the environment in which infrastructures are connected still has vulnerabilities that can affect the functioning of infrastructure assets. Those vulnerabilities are indeed 'hidden' and become apparent in different ways or at unexpected times, rooted in interdependency (the connection and coupling) with other infrastructures in complex environments (c.f., [22]).

In project management literature, researchers have endeavored to study the sources of success and challenges, and complexity has often been identified as a key challenge (see, e.g., [23]). Infrastructure projects make up a large part of this literature, as they seem particularly challenging (e.g., [24]). Dealing with complexity is of key importance, as is understanding how complexity is positioned as a crucial driver of project success. As infrastructures in recent decades have increasingly become interdependent in urban

areas [25] and projects now involve an increasing variety of stakeholders [26,27], understanding complexity and its role becomes a greater challenge than it has been historically: "We as a society have evolved a complexity in these [infrastructure] systems–in particular their complex interconnections–that makes them difficult to understand" [28] (p. xiii). Understanding the complexity that contributes to the 'hidden' vulnerabilities early in a project that, e.g., has implications for the robustness of the design(s) of the infrastructure(s), seems particularly helpful to interdependent infrastructure projects.

This article builds on three layers of complexity. First is the *analytical perspective* of mathematical systems thinking that sees complexity in systems with more nodes, links, and interdependencies [e.g., [29]]. As an example, the road network of a town is less complex to optimize than that of a city, simply because it has less links, nodes, and interdependencies. Second is the *technical perspective* on infrastructure complexity that adds a system-of-systems element. As an example, the electrification of mobility ties mobility infrastructures with flows (interdependencies) over roads (links) between cities (nodes) to power delivery (interdependencies) from centralized (power stations) and decentralized (windmills and solar panels) with the grid, with mutual interdependencies requiring up to 33 percent more power if it is also used for mobility [30]. Here, the system boundaries must be extended in decision processes to be meaningful with higher complexity [31] and more nodes, links, and more varied interdependencies (capacity, economics, and governance) [c.f., [32]]. The third layer of complexity is the *human perspective* to complexity: the socio-technical system view. This approach is about how actors need to develop a shared understanding during the decision-making processes in infrastructure projects that increasingly cross classic infrastructural boundaries [27]. To summarize, the first layer is about the complexity of the structure of a network, the second layer is about the interdependencies between prior independently viewed technical networks, and the third layer is about the human decision-making around these (now more connected) networks. Overall, the increase in complexity is the interlinking and requirements of the increasingly interconnected and interdependent infrastructures.

Although many conceptual overviews of complexity exist (e.g., [23,33–35]) with varying emphasis on technical and organizational elements, internally, and externally, the understanding and application of the concept of complexity in empirical analysis is hardly studied. Consequently, such a collection of reported empirical observations, clarifying the understanding of complexity in collaborative infrastructure projects, does not currently exist. Addressing that research gap is the goal of this article (see also [36] (p. 108)), and therefore this article asks the research question: How is complexity considered in (academic) literature, based on empirical studies about collaborative infrastructure projects? This article seeks evidence in the available scientific literature on how infrastructure organizations consider complexity through a systematic literature review (SLR) using the PRISMA method. An SLR reduces the effect of bias on the review findings [36] (p. 109). This article aims to create a comprehensive overview of empirical insights on how to deal with complexity, and of the literature's understanding of the impact that complexity has on such projects.

This article is structured as follows: Section 2 explains the chosen method for the systematic literature review, and how it was applied. Section 3 explains the findings and subsequent results of the structured literature review and the comparison of the findings with those elsewhere in scientific literature. Section 4 discusses the results, and Section 5 concludes the study.

2. Methods

This section introduces the approach to the SLR. Section 2.1 will present the systematic review choice made, Section 2.2 the development of the search query, Section 2.3 the query that was used for the search, and Section 2.4 the screening process. Detailed descriptions of the search processes are provided in Appendices A–D.

2.1. Systematic Review

To provide an overview of the empirical data, this article employs a systematic literature review (SLR). The SLR method was developed in response to criticism of the level of transparency and replicability, as well as the claims to the level of representation of reviews of academic literature in more 'traditional' forms of literature review (c.f., [37]). This article employs the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method, which advocates a particular format to conduct a standardized, transparent, and replicable analysis of the literature [38]. With this method, this article scanned scientific literature in search of published, peer-reviewed empirical data that reports on dealing with complexity in the infrastructure domain and filtered the searches in a structured, step-by-step manner. The PRISMA 2020 Checklist is provided in the Supplementary Materials (File S1).

2.2. Defining the Search Query

PRISMA requires a search query with a set of keywords that produces a dataset of all articles which contain or report on case studies (i.e., first-hand empirical data), as well as data overviews reported on from case studies done by other researchers (i.e., second-hand empirical data). This article mainly used the multidisciplinary databases of Web of Science (Clarivate, London, UK), Scopus (Elsevier, Amsterdam, The Netherlands), and to some degree OpenAlex (OurResearch, a non-profit organisation) to compile the dataset. Web of Science and Scopus are well-established and often-used online scientific libraries that index peer-reviewed, published articles, while OpenAlex is a relatively new library (launched in 2022). The use of more than one library allowed for a broader strategy and secured the inclusion of as many relevant articles as possible. To ensure that the search query produced useful results in the context of the research interest of this article and collected the relevant literature in the dataset, a so-called pre-search was conducted to identify and subsequently refine the keywords for the search query in the final search, i.e., for the review itself. The pre-search was conducted by the first author of this article and was discussed and approved by the other authors of this article. A detailed description of the pre-search can be found in Appendix A.

2.3. The Final Search

The keywords from the pre-search were applied for the final search in Web of Science (WoS), Scopus, and OpenAlex (OA). Scientific articles use different terms to describe similar topics and fields and considering that fact, synonyms were added to the keywords as a method to ensure the inclusion of as many relevant articles as possible. The same search query was used in each library, and the search parameters were kept as identical as possible to ensure replicability and coherency. The final search was conducted by the main author of this article and was discussed, considered, and approved by the other authors of this article. The full search strings can be found in Appendix C.

2.4. Screening Process

With the determination of keywords and the database searches, the dataset containing the relevant literature was developed. Until this step, efforts were primarily focused on obtaining a literature set that was as large as possible to do justice to the all-encompassing

nature inherent in the SLR method and objectives of the literature research. From the moment the dataset was determined, a second crucial phase in the SLR took over—that is, the screening process. An overview of the systematic literature review process can be found in the PRISMA flowchart in Figure 1 below. The figure shows the process of reducing the total amount of articles found in the final search, and the following screening process that led to the final 43 sampled articles. In other words, the flowchart is a visualized representation of the steps made to create the sample that will be analyzed further. The screening process was conducted by the main author of this article. Further establishment of the categorization of the sampled articles was conducted together with the rest of the authors of this article to create intersubjectivity and to re-establish the validity of the choices. A detailed description of the screening process itself can be found in Appendix B.

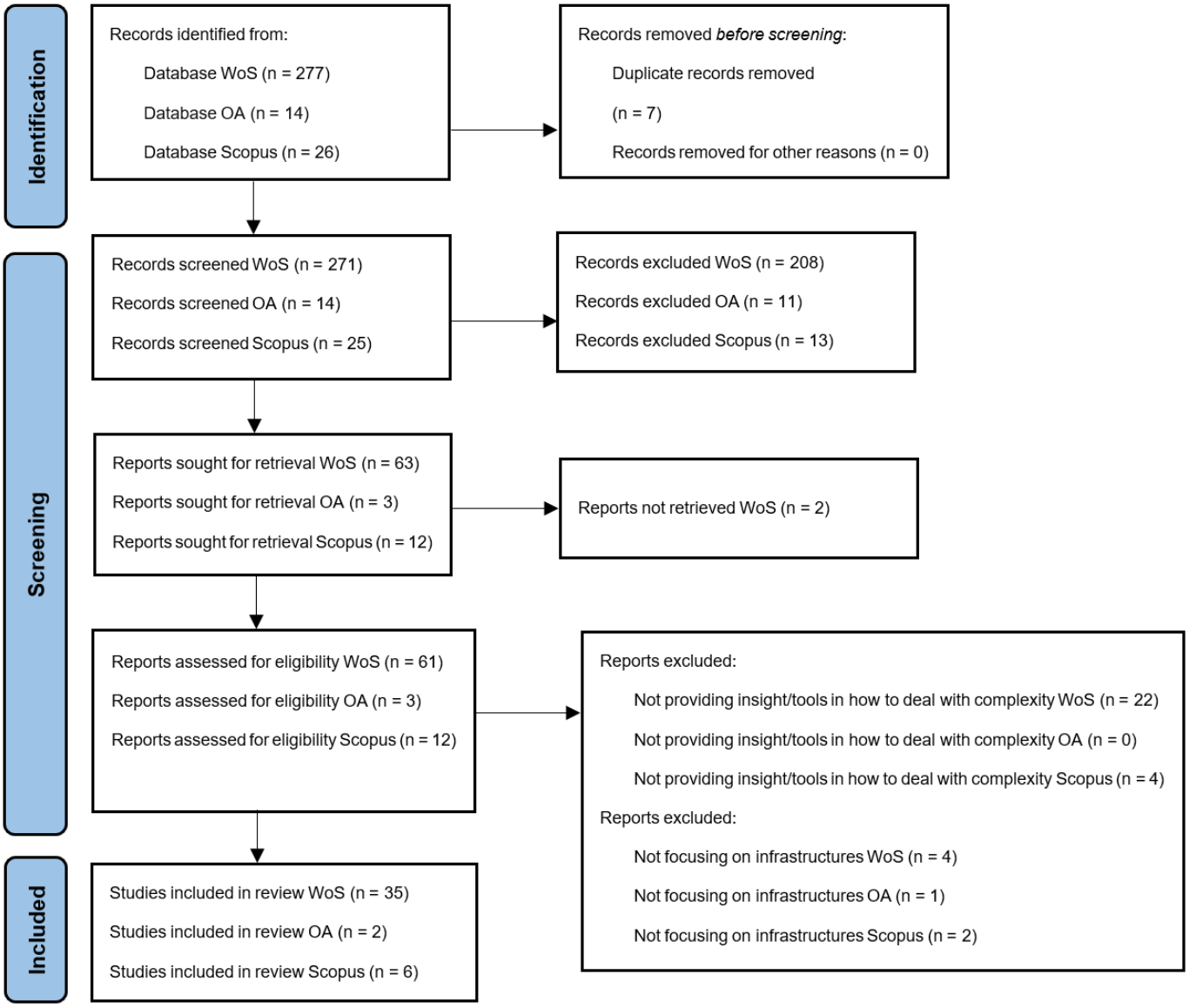

Figure 1. PRISMA flowchart of the systematic literature reviewing process from the PRISMA 2020 statement [38].

The 43 articles that form the literature review dataset represent an overview of the empirical literature on how complexity was dealt with in collaborative infrastructure projects in three scientific libraries. It is important to note that the search only included the literature that was open access, and thus the results can vary depending on one's own access to the

different publishers. To help with the analysis of the collected literature, an Excel (Microsoft Corporation, Redmond, WA, USA) database was created. Information from all articles in the sample was registered and supplemented with additional parameters to support the parsing of the dataset. The parameters were points of interest to look for and were manually filled in while reading each article. Cells in the Excel sheet were left empty when the information of a parameter was not provided or could not be credibly interpreted, so that the representation in the Excel sheet remained objective. The Excel sheet is provided in the Supplementary Materials (Table S1). The sampled articles were manually read multiple times and analyzed to look for patterns, similarities, and/or differences to make sense of the sampled articles' focus on how to deal with complexity or lack thereof. The categories, along with the other parameters of the analysis, were inductively derived by the main author and subsequently submitted to the rest of the authors of this article. Through numerous meetings, the choices of parameters to study and the categorization of the articles' insights on how to deal with complexity were validated and re-established.

3. Results

In this section, the general characteristics of the reviewed literature are described in Section 3.1, and an overview of how the articles deal with complexity is provided in Section 3.2.

3.1. General Characteristics

3.1.1. Infrastructure

The review sample includes 43 articles that report on various infrastructure sectors. Among them are railways ($n = 9$), which includes light rail, tram, and trains; roads ($n = 8$); airports ($n = 3$); water ($n = 11$), which includes dams, water basins, urban water management, flood prevention, and wastewater; underground tunnels with cables and pipes ($n = 1$); the electricity grid ($n = 1$); urban infrastructure ($n = 2$); public infrastructure ($n = 1$); and non-specified infrastructure ($n = 7$).

3.1.2. Project Organization

Of the sample of 43, 30 articles report on more than two stakeholders being involved. Only a few articles pay particular attention to the infrastructure project setting or address the challenges related to the collaborative or interdependent aspects of the project. Two of the 43 sampled articles report on horizontal collaboration specifically, and two articles somewhat discuss horizontal collaboration. The rest of the sample either does not mention horizontal collaboration or is not specific about the type of collaboration (i.e., horizontal or vertical). In total, 13 articles do not mention or specify how (many) stakeholders are involved in the project(s) on which they report. Interestingly, 26 articles focus on networks or system-of-systems, which means that the level of which the sample looks at how to deal with complexity is mainly organizational.

3.1.3. Complexity

It is noteworthy that few articles address complexity directly. In the majority of the 43 articles, complexity turns out to be, at best, a descriptive characteristic rather than an operationalized factor. The insights provided on how to deal with the complexity are generally not explicitly stated and thus had to be interpreted. Out of the 43 articles in the sample, 11 provide a definition of complexity. The 11 articles identify and discuss different types of complexity, but do not necessarily address and operationalize the concept of those complexities. Examples include institutional complexity [39,40], complex networks [41], project and dynamic complexity [42], high complexity [27], project complexity [43], complex

systems [44], complex projects [45], technical, stakeholder, and context complexity [46], complex systems [47], and project complexities (five types) [48].

A subset of articles describe(s) the infrastructure case(s) they report on as a mega-project ($n = 5$), but only one out of those five articles defines the complexity of the mega-project explicitly. The remaining articles mention complexity as a context for the mega-project, without providing further description of the complexity. 20 articles of the sample mention complexity as an important aspect, to the extent that they include it in the title or keywords of the article. Only five of the 10 articles that use complexity as a keyword define the term, and only four of the 10 that use 'complexity' in the title do so.

3.1.4. Stakeholders

29 articles report on who the stakeholders are but are not necessarily specific about the number of stakeholders. The remaining 14 articles do not report on this. Interestingly, when considering horizontal collaboration, there are only three articles in the sample that report on this [3,27,40]. Additionally, two articles mention a siloed way of working [49] and cross-national collaboration [49] without explicitly stating that it is a horizontal or vertical form of collaboration.

3.1.5. Empirical Data

Another dimension to analyze is how many cases the sampled articles report on. Of the 43 articles, 24 articles base themselves on one case study, nine articles report on two case studies, two articles mention the use of 'multiple case studies' without further clarification, one article reports on four case studies, one article reports on six case studies, one article reports on eight case studies, and one article reports on 10 case studies. Two articles review more than 100 case studies [50], $n = 112$, [43], $n = 102$. Two articles are not specific about how many case studies they include.

In terms of geographical spread, most of the sampled articles report on cases from only the European continent ($n = 27$). Three articles include case studies from multiple continents, including the European continent. One article contains a study from the African continent, while eight articles feature cases from only the Asian continent. Two articles focus on a case study on the American continent. One article focuses on a case study from the continent of Australia, and one article is not specific about the location of their case study.

Of the sampled articles, three articles use case studies based on secondary sources [25,51,52] or use a multiple small N-case study approach [53]. Out of the remaining 40 articles, 25 articles rely exclusively on interviews as a data collection method. Four articles use both interviews and a survey. Four articles use their own interviews and a second-hand survey, meaning that the survey was performed by someone else. Four articles use one or more surveys, and two articles use only surveys. One article uses a survey in combination with a second-hand interview.

3.2. Dealing with Complexity

A final dimension to analyze is the sampled articles' suggestions on the various ways of dealing with complexity. The suggestions are somewhat distinct. Even though there is some overlap between some of the categories, such as learning and flexibility or collaboration and trust building [c.f., [4]], the way to achieve those outcomes requires different approaches. Thus, the categories are here separated. An overview of that analysis is provided in Table 1 below. The last row represents a category containing two articles that did not fit the other categories and was hence named 'other' ($n = 2$). Those two articles identify the grouping of risks ($n = 1$) and clear policy frameworks ($n = 1$) as solutions. The categories are discussed

in a descending order, based on the number of sampled articles in each category. Each category is subsequently discussed in relation to the broader literature on the topic.

Table 1. Overview of the suggestions, arranged by category.

Categories Based on Suggested Approach to Complexity	The Type of Complexity	Type of Solution	No. of Articles (*n*)	Total No. of Cases
Close(r) collaboration	Cross-sectoral * complexity and its resulting uncertainty	Organizational	11	19 **
Flexibility in the project	Structural (i.e., organizational) complexity particularly in dealing with existing procedures	Organizational	10	119 **
Understanding the project (early on)	Cross-sectoral * complexity and its resulting uncertainty	Stakeholder-oriented	7	125
Trust building	Cross-sectoral * complexity	Stakeholder-oriented	4	5 **
The project as a learning process	Unclear, but taking lessons from failure and/or success in previous projects	Organizational	4	4
Implementing digital tools	Not mentioned, unclear	Technological	3	3
Clear project leadership	Structural (i.e., organizational) complexity particularly in dealing with existing procedures	Organizational	2	6
Other	Complex interactions	Stakeholder-oriented	2	3

* Cross-sectoral is here understood as the context in which multiple stakeholders work together towards a common goal and the resulting challenges that they face are crossing the boundaries of the organizations. ** Some sampled articles in the respective categories are unclear about the number of case studies.

3.2.1. Close(r) Collaboration

The largest category of articles describes close(r) collaboration as a solution to deal with complexity in infrastructure projects. The articles mainly focus on the collaborative structure of projects, e.g., on how the tasks and responsibilities are divided between the stakeholders during infrastructure projects. Persson & Granberg [54] focus particularly on acknowledging stakeholder responsibilities in projects. According to Wang et al. [55], increased collaboration is primarily realized via communication and coordination between the stakeholders, which in turn is supported via the setting of clear goals and strategies for the project. Lahdenperä [56] concludes that a specific collaborative structure, a 'pure project alliance', helps achieve this goal and cope with complexity. Busscher et al. [48] conclude that the connecting of projects to restructure (political) project discussions would do the same for complex mobility infrastructure projects. Larsson & Larsson [3], as well as Fitton & Moncaster [57], stress the value of a particular element of the structural relationship (i.e., the collaboration), i.e., the importance of a proactive and intense level of stakeholder engagement throughout the project. Likewise, Wagner & Radujkovic [58] point at the importance of continuation of collaboration throughout the project phases, as do Røsok et al. [27], who suggest a similar collaborative approach instead of working in parallel. Zou et al. [59] advice enhancing the project cultures and focus on the relations in the project teams, and Hetemi et al. [40] focus on open communication and shared workshops to bring the participants closer to each other. Lappalainen et al. [52] suggest following an alliance project model for effective collaboration in projects with multiple stakeholders.

Complexity here seems to be considered as a generic contextual factor related to uncertainty. The articles describe how uncertainty is experienced in infrastructure projects in the absence of a broad and integrating perspective. The inclusion of more or different stakeholder perspectives via close(r) forms of collaboration brings more perspectives, resulting in more complete forms of knowledge and understanding about the project, which in turn reduces complexity. Close(r) collaboration is presented as an anticipatory solution that enables the integration of perspectives of stakeholders from the early stages in the

project through mutual understanding to circumvent poorly understood parts of reality hitting the project with uncertainty. The key authors on this mechanism are Aapaoja et al. [60] and Caron [61].

3.2.2. Flexibility in the Project

Flexibility in the project as a solution to deal with complexities receives a substantial amount of attention in the sample. However, the way in which flexibility and its workings are explained differs. Eriksson et al. [43] suggest broad, generic governance arrangements to cope with complexity. Verweij et al. [62], on the other hand, propose a more specific solution with their proposal for flexible contract structures attuned to the specific projects and their requirements. Matinheikki et al. [39] suggest a collaborative approach beyond contracting, creating a joint governance that includes key stakeholders, with a focus on social interactions among the stakeholders to facilitate flexibility. This aligns with Demirel et al. [63], but they add importance to the spotting of changes over time and have an even wider perspective on flexible coping mechanisms. Hällström et al. [64] emphasize the role of social ties early in the project to allow for flexibility. Muruganandan et al. [42] links that collaborative element to the shared capability to achieve technical stability in systems integration so that they can retain the flexibility to deal with other uncertainties. Kim et al. [65] widens that idea of preparedness adaptability to deal with changes. Pennings et al. [66] emphasize collaboration with clear ownership and embracing the possibilities that this brings for flexibility. Grafius et al. [25] and Lienert et al. [67] advise taking a step back and look further than risks in interdependent projects and recognize that projects bring with them a lot of unexplored opportunities and possibilities on all levels of the project and come up with unconventional solutions that might benefit the project.

The broader literature has a similar understanding of flexibility. The nature of infrastructure projects is that they are "inherently dynamic, facing uncertainties such as fluctuating demands, technological disruptions, and shifts in political and regulatory environments. These uncertainties demand a more flexible approach to project design and management" [68] (p. 1). Jalali Sohi et al. [69] confirm that need "Increased project complexity, project dynamics and changes in clients' requirements are a few examples that suggest the necessity for flexibility in project management in order to deliver successful projects" [69] (p. 2117). The same authors also suggest that the traditional project management approach is no longer adequate to deal with the complexity of infrastructure projects [69] (p. 2117). The wider literature also addresses governance "[...] through clever contracting, by proactively anticipating potential change in the planning phase and providing flexible contract mechanisms that enable an effective response" [63] (p. 196). In addition, they emphasize that the connotation for good or bad 'flexibility' is dependent on the stakeholder perspective [63] (p. 202).

This category treats complexity mostly as an external project characteristic manifesting itself in uncertainties. These uncertainties go beyond the classic predict-and-control-oriented project management approaches. In this category, the involvement of a variety of stakeholders (which is conceptually often considered a source of complexity) contributes positively to the capability of dealing with uncertainty through the creation of flexibility. The empirical evidence from the articles in the category suggests that, by embracing the diversity and complexity of stakeholders in projects, uncertainty and unexpected 'complexity' in projects can be overcome through shared adjustment of project goals, requirements, and designs. However, the category is much less clear and univocal in its description of how this flexibility produces solutions.

3.2.3. Understanding the Project (Early on)

The third category of articles emphasizes the importance of project managers having an early understanding of the project. The category is related to the previous categories but instead underlines the value of knowledge, *understanding*. Interestingly, although the category emphasizes a focus on understanding, the type of knowledge that seems to be considered as a solution is provided by stakeholders rather than technology and/or experts. Alade et al. [49] write about achieving a better understanding of the project and its complexity by understanding stakeholder interactions and knowledge sharing between organizations. Sun et al. [50] suggest the use of in-depth pre-investigations and the organization of cross-cultural dialogs to overcome complexity. Caldwell et al. [45] recommend spending start-up time on how the project could work and less time on formal specifications. Bekius et al. [46] claim that structured trajectories and rounds of decision-making and a focus on early trust-building can help collaborations overcome the complexity of aligning the goals and interests of various stakeholders. Uusitalo et al. [70] urge the project manager to pay close attention to trust, collaboration, and communication, as well as working towards getting all involved stakeholders to come to a similar understanding of the project and its value(s). Carhart et al. [71] suggest focusing on understanding the causal relationship between the infrastructure system and the delivery of policy outcomes. Lastly, Larsson et al. [72] suggest changing the focus on innovative projects from how (it will be made) and who (will make the construction) to what (is innovated) and why (we are doing this) as a way to improve the understanding of the project's complexities.

In the broader literature, Hertog & Westerveld [73] (p. 195) say that, "With dynamically complex systems, decision-makers have to work with limited understanding [bounded rationality] and predictability [uncertainty]". Such a 'dynamic complex system' can be a large infrastructure project. Another perspective on the importance of understanding an (infrastructure) project is that, "By understanding how complex the project is, practitioners can choose the right management approach" [69] (p. 2134). Complexity in this category is considered to be originating from limited understanding and is experienced by the decision-makers as uncertainty. This uncertainty is then countered by solutions that focus on developing better understanding and spending time on reducing complexity early on. In doing so, the solution strategy seems to emphasize anticipation and misses what the first category emphasized, the dynamic uncertainty, and how limited understanding only becomes apparent later in the projects.

3.2.4. Trust Building

One of the 'human' factors identified in the sample is about trust and trust building. Trust seems particularly required for a flexible and dynamic form of governance and control of projects in the face of uncertainty that follows from complexity. Aaltonen & Turkulainen [74] point to the importance of being aware of how socialization mechanisms affect the relations between stakeholders so that project leaders can adjust their approach(es). This adjustment is considered to be a critical capability to reduce uncertainty in the project. Aaltonen & Turkulainen [41] again urge the development of trust and social capital to manage complexity in projects. Lu et al. [75] suggest management via careful selection of partners and trust building, while Opara et al. [76] stress the importance of the process of trust building.

In the broader literature, Zwikael & Smyrk [77] say that "Trust is associated with mutual understanding, unrestricted learning, and inter-organizational knowledge-sharing and can substitute a more formal control mechanism by avoiding several types of transaction costs, while still ensuring the other party meets their obligation" [77] (p. 855). And they point to two different ways of approaching a project in the context of project governance:

"One option involves a high level of control by the project owner of the project manager's activities", versus a "[...] higher degree of trust by the project owner in the project manager by permitting him/her to make operational decisions 'on the run', thus allowing the project to progress more smoothly (with fewer interruptions)" [77] (p. 855). Weick [78] (p. 334) highlights two important reasons for trust and human interaction: "First, face-to-face contact makes it easier to assess and build trust and trustworthiness. Second, face-to-face contact makes it easier to get more complete data once the trust and trustworthiness have been established. Since people are the medium through which reliability is accomplished, signals relevant to reliability flow through them". Smolders [79] gives an overview of trust in the environment of railway projects.

Complexity is here understood (as partially above) as a result of the fragmentation of knowledge and interests, with distrust being a core factor responsible for strengthening that fragmentation. This aligns with parts of the more conceptual literature (e.g., [80,81]) that posits the fragmentation of technical knowledge and organizational interests as a key component of complexity.

3.2.5. The Project as a Learning Process

Four articles [44,47,82,83] emphasize the importance of dealing with complexity through learning. Liu et al. [44] stress dynamic and explorative learning, while Friend & Thinphanga [47] emphasize the importance of taking in the reality of projects. Sun et al. [82], in turn, point to adaptability and preparation for unforeseen events as a way for project management to 'bounce back' from changes in the project's environment. Ilgen et al. [83] focus on how learning from each other can improve an urban project's resilience in a complex changing society.

In the broader literature, Brunet [84] (p. 295) argues that it is important "to understand and document current practices in order to reflect on them and gain deeper insights about project governance". In studies on project failures, Gupta et al. [85] (p. 275) argue that "[...] learning from a project failure can play a key role in the planning and monitoring of future projects to ensure the long-term success of any organisation aiming for continuous improvement". In inter-organizational projects, Bakker et al. [86] (p. 501) discuss that, "in order to successfully transfer project knowledge, the parent organization (project owner) should be made aware of the knowledge developed in the project, recognize its value, and be able to do something with it", when considering project learning. Regarding learning processes, De Bruijn et al. [87] (p. 68), say that "They [the participants] become aware of other actors' views, participate in research trajectories, communicate intensively with other actors in the process, and so on". They argue for the further importance of seeing a project as a learning process because, "During the process, new insights will become available, facts will turn out to be different from what is generally assumed, and even normative views can change. Making binding commitments at an early stage may seriously hamper such learning processes" [87] (p. 117).

The articles in this category emphasize the various aspects of learning as a solution to cope with complexity. This can be related to the previous categories about flexibility and trust. However, it focuses on a shared learning of overall system functioning and performance beyond the borders of the (sub)systems and stakeholders.

3.2.6. Implementing Digital Tools

This category suggests coping with complexity by using digital tools. Koseoglu et al. [88] discuss a synergized virtual environment that could help in the management of a complex and siloed infrastructure project such as an airport project. According to Ganis & Waszkiewicz [89] (p. 86), "[...] digital communication is one of the key success factors

of agile project management that helps in collaboration and coordination among multiple disciplines". In a similar way, Haag et al. [90] suggests the use of software tools to help the decision-makers and decision-making processes to cope with complexity. Love et al. [91] suggest using psychological artificial intelligence to help with managing projects under deep uncertainty.

In the broader literature, Toukola & Ahola [92] (p. 10) point out that research on the use of digital tools in [infrastructure] projects is scarce but "likely to create value to the stakeholders and, furthermore, to the project". How digitization and the use of digital tools in [infrastructure] projects can contribute to the improvement of "[...] stakeholder participation in urban development projects and how digital tools may be associated with value creation in the project planning phase" [92] (p. 1) remains unexplained.

3.2.7. Clear Project Leadership

This category suggests the assignment of a 'clear' project leadership as a way of dealing with complexity. Hossu et al. [53] specify that collaborative projects benefit from having someone (a project leader) to coordinate the collaborative process(es), while Gil-Garcia & Sayogo [51] stress the importance of the project manager's role in sharing information across organizational boundaries.

From the broader literature, Roe & Schulman [28] (p. 5) expand on the type of complexity that is being addressed here: "Organizationally, these critical [infrastructure] systems incorporate a framework for management and control. This framework consists of the roles, rules, procedures, and protocols prescribing their operation and the skills their personnel (managers and operators) need to operate them". The project managers are working with and within these frameworks to deliver the project both on time and within the allocated budget. Ensuring the desired outcome, however, results in conflicts with the frameworks. Researchers have taken an interest in what could be done to aid these processes in projects and looking into where it goes 'wrong' (c.f., [85]). However, the issues following this complexity are not so easily identified, as no two projects are the same and infrastructure projects are becoming increasingly interconnected and complex (c.f., [27]).

There is an increased interest in various (project) leadership styles. "As projects are always defined by their time boundedness, their structure and composition vary to a large extent from those of a standard organization. The composition generally consists of a team with diverse expertise" [85] (p. 275). Dealing with this form of complexity is a continuous challenge that requires project managers to analyze this type of complexity and adjust their leadership. This is here seen in two ways, both reflected in the literature. First, leadership can be aimed at organizing the key lessons of the categories above, or second, leadership can be oriented at the counter-balancing approaches to the collaborative approaches in the other categories (c.f., [93]).

3.2.8. Other (Risks and Policies)

This category contains two articles that have very different foci and do not fit into the other categories. Marle & Vidal [94] (p. 189) suggest the clustering of risks to "maximise the amount of interactions within the groups", supported with the argumentation that the conducting of risk analyses "encourages people to meet together and communicate/coordinate better as a way to deal with complexity" [94] (p. 204). Finally, Anwar et al. [95] suggest clear policy frameworks as a way to contribute to stability in complex public–private partnerships (PPP) in urbanization projects. However, what makes policy frameworks clear and how such a result is obtained is not explained further. Additional literature about the two foci, clustering risks and clear policy frameworks, in the context of interdependent infrastructure projects, could not be found and will not be investigated further here.

3.3. Concluding Thoughts

The articles indicate an interrelated focus on organizing knowledge and interests to overcome complexity, mostly through anticipation (i.e., by knowing how the project works up-front), although more responsive elements (such as being flexible when needed) are identified. Complexity in these articles presents itself predominantly as a contextual trait. That is, stakeholder complexity, the fragmentation of knowledge and interests. In this regard, the sampled articles provide a different focus and emphasis on complexity. Much of the earlier literature on complexity (e.g., [96]) addresses technical complexity, but in this literature sample, that perspective seems to be sublimated into the fragmentation of knowledge on the technical assets between stakeholders.

4. Discussion

This article provides an overview of the empirical literature about how complexity is dealt with in collaborative infrastructure projects through a structured literature review (SLR). The sampled articles represent the scientific (open access) literature that addresses complexity or mentions complexity as a component to empirical case studies. The initial expectation of this research was that the sampled articles would both provide insight into the different ways of dealing with complexity, as well as learning about complexity in the collaborative environment of infrastructure projects; this includes definitions and reflections on the impact of complexities in the empirical case studies. This research uncovers the real state of how complexity is considered in the empirical literature, and the result was disappointing. Complexity, although mentioned regularly, is rarely defined and is at best treated as a general term from which uncertainty follows. The term 'complexity' is mostly a descriptive component to describe empirical studies, rather than an explicitly identified factor.

Interestingly, when the sampled articles address complexity, the complexity is generally explained in a conceptual manner without operationalization, i.e., explaining in detail what a real-life situation actually looked like. That is peculiar, since empirical studies provide excellent opportunities to study real-life situations and observe the specific details of how projects work (out). However, the sampled articles seem to ignore the details of the implications and consequences of complexity, which is detrimental to furthering the understanding of complexity in interdependent infrastructure projects.

4.1. Complexity

Although some articles [25,67,71,88] in the sample point to the importance of understanding complexity, they do not address that [25] in their recommendations. There are also examples of articles that do not address complexity, but they do talk about concepts that are typically seen as complex and challenging endeavors, such as inter-organizational information sharing [57] or multi-stakeholder environments [66]. One article even studies a mega-project and claims that such projects are 'very complex' without defining that complexity [88].

There are remarkably few examples in the sample articles that operationalize the complexity and propose how to deal with it. The complexity is mostly considered on a conceptual level. Only four articles address (somewhat) specific operationalized solutions. Koseoglu et al. [88] suggest that the stakeholders should get together and assess strategic and technical perspectives and try to understand the project from the beginning. Sun et al. [50] encourage, e.g., dialog between the stakeholders, in-depth pre-investigation of the project, and emphasize timely documenting and assessments. Røsok et al. [27] urge the stakeholders to work together rather than in parallel, as well as encourage "delving into the underlying issues of why they are not able to collaborate" [27] (p. 14). Caldwell

et al. [45] suggest spending time in the beginning on how the project could work, rather than on formal specifications.

The sampled articles are not very specific on how to deal with the complexity, and the suggestions are vague at best. To illustrate, Wang et al. [55] urge communication and coordination among the stakeholders, clear goals, and a strategic vision of projects. Bekius et al. [46] observe that well-structured weeks of decision-making contributed to building trust between the stakeholders. Gil-Garcia & Sayogo [51] suggest assigning project managers to initiate and sustain inter-organizational information sharing in complex collaborative environments. Kim et al. [65] point to the necessity of adequate preparedness for the occurrence of future threats, as well as an adaptive capacity to deal with changes in the project.

The vagueness and lack of operationalization on how to deal with complexity in the sampled articles have implications for the stakeholders who are working on interdependent infrastructure projects. If the sampled articles are given as they are to the stakeholders, they will find it hard to act upon the information that is provided. They are not given any clear indicators or instructions on what they can do (today) to (improve their way of) deal with the complexities that they face, nor have they been given any clear definitions of what complexity is and what it can look like in a project. If this gap is not bridged—that is, the translation of the scientific literature to the reality of the projects that the stakeholders work on—then there will be no improvement in dealing with complexity in collaborative infrastructure projects, and the generated scientific knowledge in the form of articles and books (figuratively) end up in a drawer or on a shelf, never to be used.

4.2. Infrastructures

The search query that was used to find the empirical data allowed for the inclusion of all types of infrastructure. The reason for this was to ensure a broader search, and to study all of the sampled articles with the same level of importance. Whereas much of the literature on, e.g., critical infrastructure protection is modeled and theoretical, this article draws on empirical data which reveals that complexity is much less understood than assumed. In a network of infrastructures where vulnerabilities and weaknesses are found in both the technical aspects of the infrastructure assets as well as in the collaboration-oriented aspect(s) of the infrastructures—that is, the hidden vulnerabilities—there is still much to learn about complexity and its impact on collaborative infrastructure projects. On the technical side of the project, there are the weak points (failing due to aging or design flaws) of the assets, the weak links between the assets, and 'attack points' for external forces (such as malicious intent or weather events) to consider. On the collaboration-oriented side, there are 'hidden' vulnerabilities found in the interaction between the actors, such as challenges from the complexities of the collaboration itself. Nevertheless, this article has found that complexity and how it contributes to projects in the form of, e.g., failure propagation in collaborative infrastructure projects is poorly understood, and it is an important point to note for the future of infrastructures. This finding feeds into the existing analysis of collaborative infrastructure projects.

4.3. Collaboration

From the sampled articles emerges a major focus on collaborative approaches to deal with complexity. This does make some sense, as complexity can be seen as the fragmentation of information and incentives between stakeholders in a situation with dependency between the parts (the projects), either technical fragmentation or stakeholder fragmentation. The focus on solving this seems to be through governance, with trust between stakeholders, early involvement, different contracts and more. Interdependencies and dynamics leading

to a fragmented understanding of integrated decision-making are mentioned, but only in a secondary manner. Answers to this issue seem to emphasize incentives (contract, trust, involvement) more than information (digital tools). Also, in a more direct sense, the complexity concept does not drive much of the analysis in these articles, as the real depth of complexity (in terms of dynamics and fragmentation, be it technical, organizational, or informational) is never really a part of these analyses. Projects are assumed to be complex to begin with, without much attention to the extent to which this is the case. The more direct management of the complexity in collaborative settings is rarely studied in-depth, if at all.

Most of the data (27 articles out of 43 in the sample) focus on case studies conducted on the European continent. Two articles include European case studies in addition to case studies from other continents. This means that European case studies dominate the sample, and this therefore has implications on the findings. The searches in the scientific libraries were phrased in a way to ensure that all articles that touch upon the topic would be included, regardless of where the case studies were conducted. The observation that European case studies make up much of the sample could mean that countries on the European continent have, until now, focused more on the topic of this article than countries from other continents. This creates some bias, since there may be differences in approaches and solutions to complexity on other continents. Additionally, 26 articles focus on networks or system-of-systems, so the level of which the sample looks at how to deal with complexity is mainly organizational. Interestingly, only two articles discuss horizontal collaboration, and two articles to some degree mention a horizontal way of working, which indicates that the concept is not given much attention in the sampled articles. This leaves a message that is two-fold: the European domination is a geographical bias that could affect the interpretation of complexity, and the organizational level being the focal point of the discussion about how to deal with complexity is biased too.

This article provides a distinction between how complexity (until now) is described as a contextual characteristic of a project and an operationalized concept that requires an analytic approach in projects, which is helpful when trying to understand (analytically) what complexity is and how it should be addressed in research and practice. Until now, complexity has been almost entirely ignored rather than analytically used as a proper aspect of the problem at hand in collaborative infrastructure projects. Complexity is not analyzed in the way that researchers in scientific literature claim, which means that research is not advancing the existing discussion about what complexity entails and what impact it has on project management. Thus, the existing literature is still not precise about how to deal with complexity, nor does it provide sufficient discussion about the topic.

Classic (infrastructure) systems' boundaries have become less helpful as the energy transition has created new and poorly understood interdependencies that need to be solved to reach the key SDGs. This article shows that the primary answer provided in the literature to deal with growing complexity is to collaborate to develop a new understanding that crosses those boundaries. This means moving towards new knowledge-driven collaborations that synergistically reshape the infrastructures on both sides to work across the now-eroding borders.

4.4. Limitations

The goal with this structured literature review was to be as thorough, unbiased, and uniform as possible. There are, however, some limitations to the research. The search strategy has some inconsistencies. The search conducted in Web of Science stops at 31 December 2023, which means that there is a two-year time gap between the search and the time that this article is published. Because the authors' university ceased the sub-

scription to Web of Science while this article was being written, the missing time-gap had to be compensated for. OpenAlex was used for this purpose, which means that the general search strategy is not fully uniform.

The search and screening processes were conducted by the main author of this article. To minimize bias, the processes were re-evaluated to secure the validity of the choices that were made and the findings from the analysis. The approach to the analysis of the sample was explorative, and the categorizations and choices of parameters were inductively derived. The sampled articles were sometimes vague in their suggestions on how to deal with complexity, and thus some interpretation had to be done to determine which (new) category would best represent the articles' suggestions.

The articles that make the sample of this SLR were chosen based on their availability, and thus only the articles that were classified as open access were included. The articles also had to be available for local downloading so that they could be thoroughly and manually studied. This leaves out a portion of the research that is potentially available and relevant to the topic under study.

4.5. Further Research Avenues

The conceptual literature on complexity starts from technical and stakeholder multiplicity (i.e., many parts, many connections) and dynamics, which limits and conditions the ability to understand and predict (e.g., [80,81,97,98]). That perspective moves the best practice away from a single-stakeholder analytical optimization to interdependent, cross-sectoral, and collaborative satisfaction. This perspective seems to be embraced by the articles that are analyzed here, but without consideration of the type, expression and dynamics of the complexities. Hardly anything is mentioned in the articles about the characteristics of complexity.

This article proposes a more critical way of thinking in the analysis of complexities in projects and evaluations of the relations between the various types of complexity, their expression in uncertainty and unpredictability, and the specific collaborative approaches that would link to them. The current lack of information on these aspects in the sampled articles makes it difficult to develop and analyze strategies to deal with complexity, especially regarding interdependent infrastructure projects. That would be the start of more integrative, comparative, and methodological literature and, in turn, would allow for a fair comparison between an empirical understanding of complexity, its impact on decision-making processes, and the existing literature on complexity.

5. Conclusions

This article fills a research gap on how complexity is considered in empirical studies about collaborative infrastructure projects. As the energy transition toward achieving a sustainable future increases the interdependencies of infrastructures for, e.g., electricity, the answers for how to deal with this growing complexity remain underdeveloped. A systematic literature review (SLR) was performed in the scientific libraries Web of Science, Scopus, and OpenAlex using the PRISMA method. The expectation at the start of this research was that the sampled articles would define, explain, and provide insights on how to deal with complexity in the management of interdependent infrastructure projects. However, the research discovered the real state of how complexity is considered in collaborative infrastructure projects, and the result was disappointing. Complexity is rarely defined or operationalized. The term 'complexity' is used regularly as a descriptive component in the sampled articles, but it lacks a clear description about its expression. This means that the development of a comprehensive collection of contingent techniques and insights on how

to understand and deal with (various forms of) complexity and their potential impact on interdependence is still far off.

The conclusion is that, in this literature, the way to act upon complexity is poorly operationalized. Collaborative decision-making is seen as a generic go-to solution, and contingencies between the types, expression, and dynamics of complexity on the one hand and approaches to the more collaborative decision-making and the solutions suggested to realize this on the other hand are not available from this analysis. Considering the future of infrastructures in a sustainable society, developing an understanding of the hidden vulnerabilities that lay in the wake of poorly understood complexities, together with working towards the development of a body of research that allows for the establishment of a relation between complexity and collaborative decision-making, seems a promising avenue forward.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su182111346/s1. Table S1 is a supplementary Excel sheet that contains data extracted from the sampled literature, that is included in this structured literature review. File S1 is the PRISM 2020 Checklist that provides details on how the structured literature review was reported on.

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Appendix A

A detailed description of the pre-search

The scientific library Web of Science was utilized in the process of conducting the pre-search. By making multiple combinations of keywords that seemed relevant to the research question asked in this article, multiple literature datasets were obtained. The final dataset was created during November 2023 and resulted from a selection of six keywords and their various combinations, making sure that as much of the literature as possible was covered in the search of the Web of Science literature database. Next, the articles had to be filtered for 'relevance', a search option in Web of Science. Each of the six searches generated different numbers of hits, and between 50 and 150 articles were scanned per search. In total, 500 articles were manually scanned. Various filtering steps were taken, which resulted in a total of 17 core articles. The keywords of the 17 articles were noted, listed, and color-coded in tables to observe patterns or repeat keywords. Some keywords were compound words, and these were abstracted and reclassified in single terms. 'Complex projects' and 'institutional complexity' are examples of compound keywords, which were reclassified as (a form of) 'complexity', and further reduced to 'complex*' to include all versions of the term in the search. Following this logic, four keywords stood out as repeat keywords: 'complex*', 'collaborati*', 'project manage*', and 'infra*'. The exception to discarding compound terms was the keyword 'project management', which seemed to provide focus on the management

of infrastructure projects. Since the goal of this structured literature review was to study open access, scientific, empirical data on how complexity is considered in the literature about collaborative infrastructure projects, and no keywords representing empirical data could be found in the pre-search at this stage, the keywords 'case stud*' and 'empiric*' were added to the list of keywords.

A complete step-by-step description of this process can be provided by the authors on request.

Appendix B

A detailed description of the final search

The final search for Web of Science was conducted on 16 January 2024. The search was done within all fields, sorted by relevance, and included articles that were open access with a publication date between 1 January 2000 and 31 December 2023. For Scopus, the search was conducted on 9 September 2026. The search was done within all fields, limited to English language and article documents, as well as all open access, with a publication date between 2000 and 2026. Additionally, Scopus has the function of filtering by keywords, and the search was thus limited to 'Empirical Analysis' and 'Case Study'. The search in OpenAlex was conducted on 10 September 2026. The search was done within works, open access with a publication date between 2024 and 2026. The search in OpenAlex was conducted to cover the two-year time gap for Web of Science, since it is no longer possible for the authors of this article to search within that library. The complete overview of the search parameters used in the Web of Science, Scopus and OpenAlex searches can be found in Appendix C.

In this phase, as many irrelevant articles as possible were excluded from the dataset. Even though the search query contains carefully selected search terms, the search had not yet filtered out articles that contain irrelevant content from the context of the research question. Web of Science, Scopus, and OpenAlex have functions that allow the user to exclude topically irrelevant articles. In Web of Science, one filters by 'category', for Scopus, one filters by 'subject areas', and for OpenAlex, one filters by 'topic'. This filtering reduced the number of articles to 277 in Web of Science, 26 articles in Scopus, and 14 articles in OpenAlex, for a total of 317 articles. The categories/subject areas/topics that were kept and excluded for all three libraries can be found in Appendix D.

The lists of articles from the three libraries required additional filtering to find the articles containing empirical data on (infrastructure) projects, as well as considering complexity. The way to do that was to first read through all the 317 titles with this article's research question in mind. The process was about finding titles that indicated that the content was about any of the search words that were used in the search query (complexity, collaboration, infrastructure, project management, case study, and empirical). Seven articles were removed as duplicates. For Web of Science, 63 articles were deemed relevant and were ticked off using its built-in function to export the articles' information to an Excel sheet. The extracted information was about the type of publication (journal or other), author(s), title, journal, and abstract. The same approach was done for Scopus and OpenAlex. For Scopus, 12 articles were deemed relevant, and for OpenAlex, three articles were deemed relevant. The two libraries had a manageable number of documents, so the information was manually extracted to the Excel sheet, instead of exporting it. This brought the total amount of articles from all three scientific databases to 78 articles in the Excel sheet. The Excel sheet is provided in the Supplementary Materials (Table S1).

To ensure continuous accessibility to the articles, the articles needed to be available for local download. Which articles are available will differ depending on the university that the researcher is affiliated with, even though the articles are classified as open access. In this research, one article was unavailable and another article was incomplete, which reduced

the total number of articles to 76. Finally, the 76 articles were manually read and screened to extract a sample that only included articles that consider infrastructure and how to deal with complexity. This process reduced the final number of articles to 43, which concludes the sample.

Appendix C

Search parameters

Web of Science

Search date: 16 January 2024

Search within: All fields

Boolean string: (complex OR intricate OR complicat* OR elaborat* OR sophisticat*) AND (collaborati* OR alliance OR joint OR joint effort* OR partner*) AND infra* AND (project manage* OR project steer* OR project alli*) AND (case stud* OR empiric*)

Publication date: 1 January 2000 to 31 December 2023

Document Types: Article

Quick Filters: Open access

Total search results after filtering the categories: 277

Query Link: https://www.webofscience.com/wos/woscc/summary/418fc318-5672-46fc-88fd-9f2e70ad070f-c5cd36de/relevance/1 (accessed on 16 January 2024)

Scopus

Search date: 9 September 2026

Search within: All fields

Boolean string: (complex OR intricate OR complicat* OR elaborat* OR sophisticat*) AND (collaborati* OR alliance OR joint OR joint effort* OR partner*) AND infra* AND (project manage* OR project steer* OR project alli*) AND (case stud* OR empiric*)

Published from: 2000 to 2026

Added to Scopus: Anytime

Document type: Article

Language: Limited to English

Open access: All open access

Keywork limitation: Empirical Analysis, Case Study

Total search results after filtering the categories: 26

Query Link: https://www.scopus.com/pages/search/publications?searchId=bb1655b9-d30b-4986-88a3-a12f7b810f22 (accessed on 9 September 2026)

OpenAlex

Search date: 10 September 2026

Search within: Works**

Boolean string: (complex OR intricate OR complicat* OR elaborat* OR sophisticat*) AND (collaborati* OR alliance OR joint OR joint effort* OR partner*) AND infra* AND (project manage* OR project steer* OR project alli*) AND (case stud* OR empiric*)

Published from: 2024 to 2026

Type: Article

Open access: Open access

Total search results after filtering the topics: 14

Query Link: https://openalex.org/works?search.title_and_abstract.exact=(complex*+OR+intricate+OR+complicat*+OR+elaborat*+OR+sophisticat*)+AND+(collaborati*+OR+alliance+OR+joint+OR+joint+effort*+OR+partner*)+AND+infra*+AND+(project+manage*+OR+pro-ject+steer*+OR+project+alli*)+AND+(case+stud*+OR+empiric*)&sort=relevance_score:desc&filter=publication_year:2024-,type:article,primary_topic.id:t10395%7Ct10430%7Ct13607%7Ct10289%7Ct11121%7Ct11939%7Ct119

86%7Ct12129%7Ct12615%7Ct12825%7Ct12895%7Ct13558%7Ct14282,open_access.is_oa:true&id=dbWiL9XJ135XMSA7UqMP7p (accessed on 10 September 2026)

* It is noteworthy to mention that asterisks were used to include all versions of the keywords, so that as many articles as possible would be included in the literature research.

** OpenAlex does not allow for a search in 'All fields', like in the other two libraries. Instead, the library applies a default search in 'Works', which is the type of literature (i.e., scholarly papers, books, articles, etc.), and includes titles, abstracts, and full texts.

Appendix D

Categories kept in Web of Science

Environmental Sciences	Telecommunications
Engineering Civil	Biodiversity Conservation
Multidisciplinary Sciences	Biotechnology Applied Microbiology
Environmental Studies	Engineering Mechanical
Management	Engineering Ocean
Green Sustainable Science Technology	Evolutionary Biology
Geosciences Multidisciplinary	Information Science Library Science
Water resources	International Relations
Construction Building Technology	Law
Engineering Industrial	Oceanography
Business	Physics Atomic Molecular Chemical
Ecology	Plant Sciences
Biochemistry Molecular Biology	Public Administration
Engineering Environmental	Agriculture Multidisciplinary
Engineering Multidisciplinary	Anthropology
Biology	Architecture
Chemistry Multidisciplinary	Automation Control Systems
Engineering Electrical Electronic	Behavioral Sciences
Marine Freshwater Biology	Biochemical Research Methods
Materials Science Multidisciplinary	Business Finance
Mathematical Computational Biology	Demography
Operations Research Management Science	Economics
Physics Particles Fields	Education Educational Research
Regional Urban Planning	Engineering Aerospace
Social Sciences Interdisciplinary	Engineering Geological
Transportation Science Technology	Engineering Marine
Urban Studies	Engineering Petroleum
Chemistry Analytical	Ethnic Studies
Chemistry Physical	Forestry
Engineering Chemical	Limnology
Engineering Manufacturing	Materials Science Characterization Testing
Geochemistry Geophysics	Mathematics
Geography	Physics Nuclear
Geography Physical	Social Sciences Biomedical
Mathematics Interdisciplinary Applications	Social Sciences Mathematical Methods
Physics Applied	Thermodynamics

Categories removed in Web of Science

Astronomy Astrophysics	Computer Science Software Engineering
Genetics Heredity	Endocrinology Metabolism
Neurosciences	Immunology
Clinical Neurology	Computer Science Cybernetics
Energy Fuels	Computer Science Hardware Architecture
Oncology	Health Policy Services

Computer Science Information Systems	Infectious Diseases
Remote sensing	Microscopy
Meteorology Atmospheric Sciences	Nutrition Dietetics
Computer Science Interdisciplinary Applications	Otorhinolaryngology
Imaging Science Photographic Technology	Paleontology
Instruments Instrumentation	Parasitology
Medicine General Internal	Pathology
Pediatrics	Peripheral Vascular Disease
Psychiatry	Pharmacology Pharmacy
Public Environmental Occupational Health	Psychology Developmental
Computer Science Theory Methods	Psychology Multidisciplinary
Health Care Sciences Services	Sport Sciences
Medical Informatics	Substance Abuse
Medicine Research Experimental	Tropical Medicine

Subject areas kept in Scopus

Business, Management and Accounting	Economics, Econometrics and Finance
Social sciences	Earth and Planetary Sciences
Environmental Science	Mathematics
Engineering	Multidisciplinary
Energy	Materials Science
Decision Sciences	

Subject areas removed in Scopus

Computer Science	Health Professions
Medicine	Neuroscience
Agricultural and Biological Sciences	Chemical Engineering
Psychology	Immunology and Microbiology
Arts and Humanities	Chemistry
Biochemistry, Genetics and Molecular Biology	Veterinary
Physics and Astronomy	Pharmacology, Toxicology and Pharmaceutics
Nursing	

Topics kept in OpenAlex

Construction Project Management and Performance	Global Energy Security and Policy
Software Engineering Techniques and Practices	Climate Change and Geoengineering
Academic Publishing and Open access	Defense, Military, and Policy Studies
European Union Policy and Governance	Environmental Law and Policy
Public Relations and Crisis Communication	Philosophy, Science, and History
Public-Private Partnership Projects	Security, Politics, and Digital Transformation
Scientific Computing and Data Management	

Topics removed in Open Alex

Historical and Archaeological Studies	Historical and Cultural Archaeology Studies
Glioma Diagnosis and Treatment	Second Language Learning and Teaching
Innovations in Medical Education	Island Studies and Pacific Affairs
Pelvic floor disorders treatments	Race, History, and American Society
Child Abuse and Trauma	Global Public Health Policies and Epidemiology
Airway Management and Intubation Techniques	Asian Geopolitics and Ethnography
Telemedicine and Telehealth Implementation	Economic Issues in Ukraine
Digital Games and Media	Caribbean History, culture, and politics
Viral Infections and Outbreaks Research	

Primary Care and Health Outcomes	Socioeconomic Development in Asia
Artificial Intelligence in Healthcare and Education	Walter Benjamin Studies Compilation
Health Sciences Research and Education	Christian Theology and Mission
Forest Management and Policy	Animal and Plant Science Education
Humor Studies and Applications	Publishing and Scholarly Communication
Ocular Infections and Treatments	International Science and Diplomacy
Obesity and Health Practices	Moronism, Religion, and History
Italian Fascism and Post-war Society	Eastern European Communism and Reforms
Zoonotic diseases and public health	Philosophy, Sociology, Political Theory
Australian History and Society	Academic Freedom and Politics

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