Challenges related to system-of-systems for greening and climate adaptation in smart cities.

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November 17, 2022

**Keywords**— System-of-systems; Digital Twins; Digital Platforms; Smart-Cities; Climate Adaptation; Green infrastructure; Empirical Study; Interviews;

**Abstract**

This paper presents the results of interviews conducted as part of the DYNASOS project. The objective was to collect challenges related to the design, implementation and management of system-of-systems (SoS) in the context of climate adaptation and greening of smart cities. 23 individuals from cities, academia, and industry were interviewed between March and May 2022 and 57 distinct challenges were collected and analyzed. Our results show that while technical issues (such as interoperability or data acquisition) persist, non-technical issues are the main obstacles. Difficulties in information sharing, effective communication, and synchronization between different actors are the most important challenges.

1 Introduction

In this paper, we present and discuss the results of interviews done during the DYNASOS project for the field of smart cities, specifically focusing on the use cases of climate adaptation and greening. The project DYNASOS, funded by the German Federal Ministry for Education and Research (BMBF), has the goal of understanding the current trends in software engineering research and to propose a roadmap for future research funding [RAS22]. In that context, six application domains were chosen. The smart city domain was one of them. Indeed, the implementation of smart city strategies requires the setting up of digital infrastructure allowing several systems (sensors, database, applications) to interact. The goal is to provide both a global overview of the city services and the possibility to host and enable an ecosystem of new services allowing a broader involvement of citizens (see for example services

[https://dynasos.de/](https://dynasos.de/)
like https://giessdenkiez.de/ or platform such as https://foodsharing.de/ or https://mundraub.org/). The supporting and underlying digital infrastructure are sometimes described as digital ecosystems or platforms [KKN+22] and belong to a larger group of what is called system-of-systems (SoS) [GSB08].

In the context of the project DYNASOS, we performed literature reviews and conducted interviews and workshops with representatives from industry and academia from the smart city domain. We specifically focused on the use case of climate adaptation and greening. Our first goal was to collect and organize challenges from the point of view of stakeholders involved at the level of city planning. The second goal is to understand how these challenges relate to Software and SoS Engineering.

This article is structured as follows. Section 2 provides relevant definitions and an overview of the challenges mentioned in the literature regarding the two areas of SoS and smart cities. Section 3 and 4 presents respectively the methodology followed and the obtained results. Section 5 presents a discussion of the results and section 6 the conclusion.

2 Definitions and Related work

2.1 System-of-systems (SoS)

Over time, the definition of a system-of-systems (SoS) has evolved [GSB08], but today most studies in that domain agree on the following definition: a system-of-systems combines multiple systems to accomplish a task that none of the systems can accomplish alone, with each constituent system maintaining its own management, goals, and resources while coordinating and adapting within the SoS to achieve the overall goals of the SoS (when these are explicitly defined). Since this first definition is relatively abstract, SoS scholars have supplemented it with a set of characteristics that help refine what a SoS is [Ma08, De05, BS06].

**Autonomy** - A constituent system has the ability to make independent decisions. This includes management and operational independence [Ma08, De05]. This means that the different systems taking part in the SoS are developed and operated by different organizations but still cooperate together.

**Heterogeneity, geographic distribution, and connectivity** - Constituent systems might be different in nature (e.g., sensors, actuators, software, etc.), with different dynamics operating at different time scales. They are generally not physically located in the same place, but are interconnected (i.e., they exchange information).

**Belonging** - Constituent systems have the right and ability to choose to belong to a SoS. Evolution and Emergence - The infrastructure, functionality, and objectives of the SoS may change over time and depend on the evolution of its constituent systems. The overall behavior of the SoS is an emergent property that depends on the interaction of its constituent systems. One type of SoS implementation that is commonplace today are digital ecosystems where constituent systems take the form of services (or app) available, for example, on a marketplace [KKN+22] (a classifications of the different types of SoS have been provided in [Ma08, DB08]).

Developing such systems presents a variety of engineering challenges. The literature on SoS [DBB20, HBB13, DNL13] and more recently on digital ecosystems [KKN+22] provide insight about challenges from the software and SoS engineering point of view. These challenges can be summarized and organized as follows: challenges on the level of SoS characteristics and quality attributes (e.g., safety, availability, interoperability, compatibility, etc.), challenges on the level of management and over-
sight (e.g., stakeholder heterogeneity, responsibilities and leadership, etc.), challenges on the level of design and implementation [DBB20, HHH13, DNL13].

### 2.2 SoS and Smart-city

Increasing urbanization and resource consumption in cities bring their own set of sustainability challenges. Smart cities attempt to address these challenges through new technologies and by connecting information from people and all elements of the city. The underlying assumption is that by using data and information technologies from various systems, smart cities are able to provide efficient services, control and process optimization. [ABD15, MC19, WC18].

The increasing digitization of cities enable the collection of large amounts of information. This can be used for monitoring and analysis, and even to develop new applications and systems to meet the city’s needs. Smart city solutions are already being used in various fields such as building management, transportation, infrastructure, health, public safety, services and governance [WC18, DL18]. Cities are by nature complex systems in which several actors, systems and domains interact together. The feedback loops that occur can create emergent phenomena that are challenging to control (see for instance [Len20]). One of the goals of smart city solutions is, if not to control the complexity of cities, at least to make it tangible. However, the interaction and connection of different systems in cities is difficult to achieve, making the implementation of smart city projects and the desired collaboration between different stakeholders slow and tedious [PL20].

The SoS approach has been explored in the field of smart cities. [CCL16] provide an example of a traffic SoS in which several systems interact with each other to provide an efficient and intelligent traffic system. The goal is to monitor, control and optimize the traffic using several sensors (number of cars, air pollution, etc.) and real-time data (traffic lights, tolls, etc.). Adjustments in the traffic light system and route optimization can help to prevent traffic jams and to reduce air pollution. The authors in [AN18] described several smart technologies that are in use in Singapore (road tolls, public transportation service, operations centers for traffic surveillance, air quality monitoring, etc.), as well as the communication networks between all kind of actors and stakeholders (including people mobility and transportation goods). The authors pointed out that there is a lack of knowledge how to connect the different systems and domains. Another example is provided in [EM21] and focuses on sustainable cities by adapting the transportation within the city. The idea considered the use of autonomous components and real time adaptation to drive energy efficiency. The vision is a completely autonomous city with autonomous interacting systems. The authors in [PLG20] applied a SoS thinking approach to develop a governance dashboard for smart streetlights applying a SoS framework developed in [LTG19]. For a successful dashboard, the authors mentioned that efficient communicating information and improving data accuracy are necessary.

Finally, [DL18] establishes a list of requirements for what a smart city should provide. This includes end-to-end experience, architecture, security and privacy and infrastructure requirements. The authors mentioned specific requirements like the fact that data collection has to be possible from multiple sources, need to be manageable, transformable and storable for specific applications. Different systems, technologies, and services must be integrable through standardization and interoperability, so that different domains of the city, and their systems and data, can be used within a SoS.
3 Materials and Methods

A purposive sampling approach was conducted, including stakeholders from cities, academia and industry. The objective was to identify people working in the smart city field who are interested in the following topics: sustainability and resilience, climate change adaptation and protection, and blue-green infrastructures and nature based systems. Therefore, the sampling was carried out in the following areas: management and development of smart cities, sustainability projects in cities and applied sciences, geographic information systems, climatology and meteorology, information technology, hydrology and agriculture. All of the interviewees were working on specific tasks related to smart cities and technologies for sustainability on a daily basis, providing comprehensive coverage of smart city challenges and a variety of perspectives. Their expertise has allowed for a better understanding of the decision-making processes of cities and the complexity of the different areas to be taken into account.

In total, we conducted 21 semi-structured interviews from March to May 2022, with two interviewers for each interview. The content was captured through written notes and recordings. Recordings were used only with the consent of the interviewee. The duration of each interview was 60 minutes.

The interviews were driven by the following guiding questions:

1. What are the current challenges and research questions in the development of SoS in the domain of sustainability, climate adaptation and greening in smart cities?

2. What are exemplary use cases to explain these challenges and research questions?

3. What are representative example systems that can be used to make these use cases tangible?

Since the system-of-systems approach was not necessarily known (at least by that name) by the interviewees, we first created a mock up (“vision”) of what a system-of-systems approach to managing green and blue infrastructure in a city might look like. The interviews were then conducted in 4 parts. The first part was devoted to explaining the purpose of the interviews and the context (DYNASOS project). The second part was used to introduce the interviewees and interviewers and to collect demographic data. In the third part, we presented our ”vision” of a SoS for smart and we collected comments and feedback. And finally, the last part was devoted to identifying current challenges, use cases and exemplary systems. In summary, we collected the following information:

- Demographics.
- Feedback about the presented vision, use case, and motivation.
- Existing systems, actors, stakeholders.
- Current challenges.
- Existing and possible SoS solutions.
- Further applications of SoS.

Most interviewees acknowledged that their day-to-day projects are indeed related to interacting systems and have to deal with many different stakeholders, but very few were familiar with the concept of “system-of-systems” and what this can actually bring them.
4 Results

4.1 Demographics

| Country | Germany (19), Austria (2), Estonia (1), Singapore (1) |
|---------|------------------------------------------------------|
| Work context | City (6), University (5), Applied research (6), Private company (6) |
| Role | Project leader (8), Manager (6), Researcher (4), Professor (3), CEO (1), Student (1) |

Table 1: Summary of the interviewees demographics. The number of interviewees for each category is shown in parentheses.

Table 1 summarizes the demographics information, the following section provides more details.

We performed interviews with a total of 23 experts from Germany (19), Austria (2), Estonia (1), and Singapore (1) from March 2022 until May 2022.

From a context perspective, six persons were working directly in cities (Köln (2), Kaiserslautern (1), Mönchengladbach (1), Freiburg (1), Iserlohn (1)); five persons in universities (Hochschule Weihenstephan-Triesdorf (1), Tallinn University of Technology (1), Leibniz Universität Hannover für Meteorologie und Klimatologie (1), Universität für Bodenkultur Wien (1), and NTU’s Asian School of the Environment (1)); six persons in applied research institutions (Fraunhofer IAO (1), Fraunhofer UMSICHT (2), Deutsches Institut für Urbanistik DIFU (3)); and six persons in private companies (IP SYSCON GmbH (2), berchtoldkrass spaco&options (2), GRUNSTATTGRAU (1), and Kompetenzzentrum Wasser Berlin KWB (1)).

From a position (role) perspective, eight persons were working as project leaders, six as managers, four as researchers, three as professor, one as CEO, and one interviewee was student at the time of the interviews.

Finally, we asked participants to name their main areas of interest and the topics they are working on (hereinafter referred to as "topics of interest"). Table 2 presents an overview of the interviewees’ topics of interest. We first used this information to see if we had missed any important topics for our case study.

4.2 Challenges

In total, we collected a set of 57 distinct challenges that we organized into 8 categories: data, people, system and software, system-of-system (SoS), work structure and processes, resource conflicts, complexity, and legal aspects. Table 3 provides a short description of each category and the number of distinct challenge for each category.

Note that not all interviewees mention the same number of challenges. For each interviewee, we counted how many distinct challenges they mentioned. The resulting distribution is shown in figure 1.

We found that many of the challenges mentioned belonged to the categories "data", "people", "systems and software", "SoS", and "structure and work processes" (see table 3). This can be explained by the fact that most of the interviewees were from cities or worked closely with cities and were involved in smart city projects. Therefore, the number of distinct challenges identified in these categories was high in relation to resource conflicts, complexity, and legal aspects. Although the interviewees had no or
very little contact with the SoS engineering field, they directly recognized the similarity between the SoS approach and their current projects. In addition, interviewees did not directly refer to SoS when mentioning their challenges, we classified them as "SoS" later.

5 Discussion

5.1 Interpretation of the interview results

First, the amount of challenges collected and the details of each category show the complexity of implementing an SoS in the smart city context.

The fact that challenges in categories "system and software" and "SoS" were ranked on average lower show us that challenges of technical nature, even if they do exist and need to be solved, are not the main pain points in implementing SoS in smart cities. What often came out of our discussions were that silos are a major challenge. These can be silos at the level of data: not knowing who owns what data
| Category                  | Description                                                                                                                                                                                                 | Distinct challenges |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Data                     | Challenges related to the data lifecycle (e.g., acquisition, exchange, preparation, analysis, quality)                                                                                                       | 12                  |
| People                   | Challenges related to people (e.g., communication, skills, staffing, personal and political relations between departments)                                                                                       | 11                  |
| System and software      | Challenges related to system and software (e.g., legacy systems, missing features, user-friendliness)                                                                                            | 11                  |
| SoS                      | Challenges related to the system-of-systems approach (e.g., distributed responsibility, security, impact)                                                                                          | 8                   |
| Work structure and processes | Challenges related to the current work structure (e.g., agility, incentive to collaborate, transparency, processes incompatibility)                                                                 | 8                   |
| Resource conflicts       | Challenges related to resource conflicts in cities (e.g., land use, costs)                                                                                                                                   | 3                   |
| Complexity               | Challenges related to complex systems and emergent phenomena (e.g., foreseeability, non-linear feedback loops)                                                                                           | 2                   |
| Legal aspects            | Challenges related to the different legal and regulatory aspects in cities (e.g., data privacy, regulations)                                                                                              | 2                   |

Table 3: Number of distinct challenges per category
Figure 1: Distribution of the number of challenges mentioned by each interviewee. Most of the interviewees mentioned between 13 and 16 challenges (the median is 15). The minimum number of challenges mentioned by a single interviewee is 5 and the maximum is 27.

Figure 2: Distribution of the number of times a given challenge was mentioned by the interviewees. Half of the challenges were mentioned less than 5 times by all the interviewees (the median is 5, $Q_1 = 2$, $5$ and $Q_3 = 7$). Two challenges were cited each by 14 interviewees (max = 14). These two challenges concerns problems due to data silos and the communication between different actors.
| Category                        | Name                                                                 | Mentions   | Rank |
|--------------------------------|----------------------------------------------------------------------|------------|------|
| Data                           | Data silos                                                           | 14 (87.5%) | 1    |
| People                         | Communication between different actors or stakeholders.              | 14 (87.5%) | 1    |
| Work structure and processes   | Stakeholders with their own plans, goals and interests, who are not willing to cooperate with each other. | 12 (75%)   | 3    |
| Data                           | Data capture                                                         | 12 (75%)   | 3    |
| Complexity                     | Model, measure and understand causal effects                         | 12 (75%)   | 3    |
| Work structure and processes   | Fixed structure of the organization                                  | 11 (68.75%)| 6    |
| Resource conflicts             | Costs and funding                                                    | 11 (68.75%)| 6    |
| Legal aspects                  | Data protection                                                      | 10 (62.5%) | 8    |
| People                         | Staff shortages                                                      | 10 (62.5%) | 8    |
| System and Software            | Interoperability                                                     | 9 (56.25%) | 10   |
| Data                           | Data sharing                                                         | 8 (50%)    | 11   |
| People                         | Acquire competencies                                                 | 8 (50%)    | 11   |
| SoS                            | Communication about the potential impacts of such systems             | 8 (50%)    | 11   |

Table 4: Most cited challenges: challenges that were mentioned by half of the interviewees. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).
| Category                        | Name                                                                 | Mentions       | Rank |
|--------------------------------|----------------------------------------------------------------------|----------------|------|
| Work structure and processes   | Stakeholders with their own plans, goals and interests, who are not willing to cooperate with each other. | 12 (75%)       | 3    |
| Work structure and processes   | Fixed structure of the organization                                 | 11 (68.75%)    | 6    |
| Work structure and processes   | Lengthy processes                                                    | 6 (37.5%)      | 17   |
| Work structure and processes   | High workload                                                        | 6 (37.5%)      | 17   |
| Work structure and processes   | Agreement and coordination between stakeholders takes too long        | 5 (31.25%)     | 23   |
| Work structure and processes   | Transparency                                                         | 4 (25%)        | 31   |
| Work structure and processes   | Incompatible processes                                               | 4 (25%)        | 31   |
| Work structure and processes   | Organizations are conservative                                       | 2 (12.5%)      | 44   |

Table 5: Challenges from the category: work structure and processes. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).

| Category | Name                                           | Mentions       | Rank |
|----------|------------------------------------------------|----------------|------|
| Data     | Data silos                                     | 14 (87.5%)     | 1    |
| Data     | Data capture                                   | 12 (75%)       | 3    |
| Data     | Data sharing                                   | 8 (50%)        | 11   |
| Data     | Data quality - accuracy                        | 7 (43.75%)     | 14   |
| Data     | Data quality - timeliness                      | 7 (43.75%)     | 14   |
| Data     | Data governance, data sovereignty               | 6 (37.5%)      | 17   |
| Data     | Data quality - completeness                    | 5 (31.25%)     | 23   |
| Data     | Data quality - resolution                      | 5 (31.25%)     | 23   |
| Data     | Automation of data extraction, processing and use | 5 (31.25%)       | 23   |
| Data     | Data preparation                               | 4 (25%)        | 31   |
| Data     | High risk and uncertainty in the application of AI | 3 (18.75%)   | 39   |
| Data     | Data semantics                                 | 2 (12.5%)      | 44   |

Table 6: Challenges from the category: data. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).
| Category | Name                                                                 | Mentions       | Rank |
|----------|----------------------------------------------------------------------|----------------|------|
| People   | Communication between different actors or stakeholders.              | 14 (87.5%)     | 1    |
| People   | Staff shortages                                                      | 10 (62.5%)     | 8    |
| People   | Acquire competencies                                                 | 8 (50%)        | 11   |
| People   | Change management                                                    | 6 (37.5%)      | 17   |
| People   | Technology affinity                                                  | 5 (31.25%)     | 23   |
| People   | Personal or political problems between different stakeholders         | 5 (31.25%)     | 23   |
| People   | Network effect between stakeholders                                  | 4 (25%)        | 31   |
| People   | Acceptance - open data, citizen data science                          | 4 (25%)        | 31   |
| People   | Acceptance - generic                                                 | 4 (25%)        | 31   |
| People   | Acceptance - fear of nature                                           | 2 (12.5%)      | 44   |
| People   | Acceptance - fear of surveillance and loss of control                | 2 (12.5%)      | 44   |

Table 7: Challenges from the category: people. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).

| Category | Name                                                                 | Mentions       | Rank |
|----------|----------------------------------------------------------------------|----------------|------|
| SoS      | Communication about the potential impacts of such systems            | 8 (50%)        | 11   |
| SoS      | Accountability, governance                                           | 6 (37.5%)      | 17   |
| SoS      | Coupling of different models                                          | 5 (31.25%)     | 23   |
| SoS      | Change in functionality                                              | 4 (25%)        | 31   |
| SoS      | Security                                                             | 4 (25%)        | 31   |
| SoS      | Autonomous systems have to interact with living systems (high uncertainty) | 3 (18.75%) | 39   |
| SoS      | Evaluation                                                           | 2 (12.5%)      | 44   |
| SoS      | Nature-based systems not considered first-citizen                    | 1 (6.25%)      | 52   |

Table 8: Challenges from the category: system-of-systems (SoS). The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).
| Category       | Name                                      | Mentions       | Rank |
|---------------|-------------------------------------------|----------------|------|
| Systeme and Software | Interoperability                           | 9 (56.25%)     | 10   |
| Systeme and Software | Robustness                                | 5 (31.25%)     | 23   |
| Systeme and Software | Missing software functionalities           | 3 (18.75%)     | 39   |
| Systeme and Software | Usability                                 | 3 (18.75%)     | 39   |
| Systeme and Software | Multifunctionality                        | 2 (12.5%)      | 44   |
| Systeme and Software | Speed                                     | 2 (12.5%)      | 44   |
| Systeme and Software | Unused communication tools                | 1 (6.25%)      | 52   |
| Systeme and Software | Computational effort for simulation       | 1 (6.25%)      | 52   |
| Systeme and Software | Existing systems each have a single predefined and fixed function | 1 (6.25%) | 52 |
| Systeme and Software | Existing hardware limitations             | 1 (6.25%)      | 52   |
| Systeme and Software | Understanding                             | 1 (6.25%)      | 52   |

Table 9: Challenges from the category: system and software. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).

| Category       | Name                                      | Mentions       | Rank |
|---------------|-------------------------------------------|----------------|------|
| Complexity    | Model, measure and understand causal effects | 12 (75%)      | 3    |
| Complexity    | Unpredictability                          | 2 (12.5%)      | 44   |
| Legal aspects | Data protection                           | 10 (62.5%)     | 8    |
| Legal aspects | Different regulations need to be followed for SoS | 6 (37.5%) | 17 |
| Resource conflicts | Costs and funding                       | 11 (68.75%)    | 6    |
| Resource conflicts | Conflict between different land uses      | 7 (43.75%)     | 14   |
| Resource conflicts | Nature-based systems have different needs over time | 3 (18.75%) | 39 |

Table 10: Challenges from the categories: complexity, legal aspects, and resource conflicts. The "mentions" column shows the number of interviewees that mentioned a given challenge and its corresponding percentage (in parenthesis). The "rank" column shows the overall ranking of each challenge (equal "mentions" values have the same rank).
and having difficulties to access it ("data silos", "data sharing" see table 6); or silos at the level of processes and work structure: not being able to properly communicate or synchronize with other departments ("stakeholders with their own plans...", "fixed structure..." see table 5). These are challenges that are common to many AI or data-driven types of projects [RA20, HJTV22] and Research and practical feedback in these types of projects could offer solutions (see for example the SE4AI domain [MFBB22]). Several interviewees mentioned that the application of agile methods could be a solution. Other challenges, that also happen in AI and data-driven projects, that were mentioned during the interviews are capturing data, pre-processing data, managing data quality and usage. The main cause of these challenges is the lack of skilled manpower, the costs of implementing such solutions, but also the very nature of data-driven projects: the potential of data might not be known in advance and different quality levels and resolution might be needed by different stakeholder.

5.2 Comparison with challenges found in the related work

We identified several papers in the related work that also described challenges related to SoS and smart cities. [AN18] and [CCL16, CCLB17], each identified eight challenges and opportunities related to mobility in Smart Cities. [MKK21] identified 11 challenges from the perspective of digital twins.

The first aspect mentioned by these papers concerns the complexity related to the interoperability of different heterogeneous systems. [CCL16, CCLB17] identified scale, that is, the number of devices being connected in cities, architecture, interoperability, and heterogeneity as main challenges and were also identified in our interviews. [MKK21] and [Len20] identified the need of standardization as one of the main issues when implementing a SoS. This was also a major concern from the interviewees.

All the authors recognized the huge potential of connecting the systems and make use of the data and information and identified challenges regarding the data [CCL16, CCLB17, MKK21]. The ability to safely share information between systems is a challenge that is still not solved. In [CCL16, CCLB17], the authors did not consider data quality issues raised by the interviewees and [MKK21]. In addition, the amount of data available and the ability of systems and analytics to process it into useful and meaningful decisions is a concern that was cited by [CCL16, CCLB17] as well as our interviewees. The use of AI and its potential risks were only mentioned in our study. [CCL16, CCLB17] and [WC18] identified challenges related to the multitude of stakeholder, their disciplines and domains, for instance conflicts between stakeholders. This has also been confirmed with the conducted interviews. Work structures and processes have been identified as challenging. For a SoS project to work, processes need to be compatible, transparent and flexible which is often not possible due to the current structure of a city. Additionally, stakeholders need to be willing to adapt to new systems (socio-technical effects) [AN18].

The lack of communication and visualization tools can lead to misunderstandings, resulting in resistance to new technologies and new work processes, according to [WC18]. As [Len20] mentioned, the accessibility to information systems and services for the various types of stakeholders need to be established to further increase the willingness. Furthermore trust of the users and new responsibilities were mentioned. In the end, communication not only between the systems but also between the different stakeholders are essential according to the interviewees and [MKK21]. These aspects were also identified in the interviews, but it was possible to address other issues related to social aspects, such as fears of staff shortages, lack of skills, lack of
acceptance of open data and citizen data science, or the loss of control implied by the new technologies. The social aspects that need to be taken into account in cities are even more complex if we also consider the technical aspects. Another aspect indicated by [Len20] are the need for a strong political support and a cultural change, while [MKK+21] focused on the development of skills to deal with the new technologies and processes.

### 5.3 Sustainability

Cities are still struggling to become more sustainable. While smart city strategies focus primarily on topics related to governance, infrastructure, and digital technologies, topics related to sustainability and especially the environment are rare. Even though sustainability is a key driver for the interviewees, they identified implementation as a major challenge due to the fixed structures of the city, their complexity, and the objectives of different stakeholders. The same observations were made by Joss et al. [JSS+19], also indicating that there are only a handful of smart cities that focus on the environment and sustainability, particularly green infrastructure.

According to our interviews, the lack of information regarding the structure and the land-use of a city to identify areas where greening would be possible hampers the development of a more sustainable city.

In addition, the complexity induced by the involvement of different stakeholders, their potentially conflicting interests and their current structures and work processes must be addressed to facilitate and find appropriate management strategies for sustainability. The complexity of the city must be understood and reduced in order to make decisions for greater sustainability. A structured holistic approach such as SoS engineering could be helpful.

One example is the project GreenTwin[s] between the cities of Tallinn and Helsinki, which is being developed for a more democratic, resilient and green city. It takes into account several systems that influence green spaces in cities and the systems that are influenced by green spaces (urban climate, air pollution, human health, energy system, etc.) The green digital twin contributes to a better consideration of ecology in planning processes. The inclusion of a wide range of data allows for models and simulations so that the cities decision-making processes impact on sustainability can be better understood.

### 6 Conclusions

This paper presents and discusses the results of 23 interviews done between march and may 2022 within the context of the DYNASOS projects. We specifically focused on the use case of climate adaptation and greening in smart cities. We were able to collect 57 distinct challenges, to organize them, and to compare them with the one founds in the related work. Our findings suggest that while many technical issues remains (e.g., interoperability, data silos), the real blockers are non-technical (what [DNL+13, NLA18] referred as "human aspects" and [DBB20] as "management and oversight challenges"): conflicts between stakeholders, inappropriate and inflexible work structures, etc. Challenges mentioned in the SoS literature such as the control of emergent phenomena, having to take into account multiple models are, for now,

[https://www.tallinn.ee/en/valisprojektid/greentwins-tallinn-helsinki-digital-green-model](https://www.tallinn.ee/en/valisprojektid/greentwins-tallinn-helsinki-digital-green-model)
less of a concern for smart cities practitioners. Finally, it is worth noting that many SoS development initiatives have been developed [LSD+17] but it seems that very few of them were applied in the context of smart cities. Many of the people we spoke to commented that they don’t know what the benefits of a SoS approach are, but the projects they are running and the problems they face are exactly those of system-of-systems. An evaluation of SoS development initiatives (such as the ones presented in [LSD+17]) in the context of smart cities would greatly help practitioners

References

[ABD15] Vito Albino, Umberto Berardi, and Rosa Dangelico. Smart cities: Definitions, dimensions, performance, and initiatives. Journal of Urban Technology, 22:2015, 02 2015.

[AN18] J. Axelsson and S. Nylander. An analysis of systems-of-systems opportunities and challenges related to mobility in smart cities. pages 132–137, 2018.

[BS06] John Boardman and Brian Sauser. System of systems-the meaning of of. In 2006 IEEE/SMC International Conference on System of Systems Engineering, pages 6–pp. IEEE, 2006.

[CCL+16] E. Cavalcante, N. Cacho, F. Lopes, T. Batista, and F. Oquendo. Thinking smart cities as systems-of-systems: A perspective study. 2016.

[CCLB17] E. Cavalcante, N. Cacho, F. Lopes, and T. Batista. Challenges to the development of smart city systems: A system-of-systems view. pages 244–249, 2017.

[DB08] Judith S Dahmann and Kristen J Baldwin. Understanding the current state of us defense systems of systems and the implications for systems engineering. In 2008 2nd Annual IEEE Systems Conference, pages 1–7. IEEE, 2008.

[DBB20] C. E. Dridi, Z. Benzadri, and F. Belala. System of Systems Modelling: Recent work Review and a Path Forward. ICAASE 2020 - Proceedings, 4th International Conference on Advanced Aspects of Software Engineering, 2020.

[DeL05] Daniel DeLaurentis. Understanding transportation as a system-of-systems design problem. In 43rd AIAA aerospace sciences meeting and exhibit, page 123, 2005.

[DL18] M. Daneva and B. Lazarov. Requirements for smart cities: Results from a systematic review of literature. volume 2018-May, pages 1–6, 2018.

[DNL+13] H. Dogan, C. Ncube, S. L. Lim, M. Henshaw, C. Siemieniuch, M. Sinclair, V. Barot, S. Henson, M. Jamshidi, and D. DeLaurentis. Economic and societal significance of the systems of systems research agenda. Proceedings - 2013 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2013, 2013.

[EM21] A. Elbashir and H. Mahmoud. A vision for smart and sustainable cities. IET Smart Cities, 3(4):185–188, 2021.
[GSB08] Alex Gorod, Brian Sauser, and John Boardman. System-of-systems engineering management: A review of modern history and a path forward. *IEEE Systems Journal*, 2(4):484–499, 2008.

[HBB+13] Sharon A Henson, MJD Henshaw, Vishal Barot, Carys E Siemieniuch, Murray A Sinclair, Mo Jamshidi, Huseyin Dogan, SL Lim, Cornelius Ncube, and Daniel DeLaurentis. Towards a systems of systems engineering eu strategic research agenda. In *2013 8th International Conference on System of Systems Engineering*, pages 99–104. IEEE, 2013.

[HJTV22] Jens Heidrich, Andreas Jedlitschka, Adam Trendowicz, and Anna Maria Vollmer. Building ai innovation labs together with companies, 2022.

[JSS+19] Simon Joss, Frans Sengers, Daan Schraven, Federico Caprotti, and Youri Dayot. The smart city as global discourse: Storylines and critical junctures across 27 cities. *Journal of Urban Technology*, 26(1):3–34, 2019.

[KKN+22] Matthias Koch, Daniel Krohmer, Matthias Naab, Dominik Rost, and Marcus Trapp. A matter of definition: Criteria for digital ecosystems. *Digital Business*, 2(2):100027, 2022.

[Len20] U. Lenk. Smart cities and mbse: Comparison of concepts. pages 169–174, 2020.

[LSD+17] C. A. Lana, N. M. Souza, M. E. Delamaro, E. Y. Nakagawa, F. Oquendo, and J. C. Maldonado. Systems-of-systems development: Initiatives, trends, and challenges. *Proceedings of the 2016 42nd Latin American Computing Conference, CLEI 2016*, 2017.

[LTTG19] O.L. Lee, R.I. Tay, S.T. Too, and A. Gorod. A smart city transportation system of systems governance framework: A case study of singapore. pages 37–42, 2019.

[Mai98] Mark W Maier. Architecting principles for systems-of-systems. *Systems Engineering: The Journal of the International Council on Systems Engineering*, 1(4):267–284, 1998.

[MC19] J. Monstadt and O. Coutard. Cities in an era of interfacing infrastructures: Politics and spatialities of the urban nexus. *Urban Studies*, 56(11):2191–2206, 2019.

[MFBF+22] Silverio Martínez-Fernández, Justus Bogner, Xavier Franch, Marc Oriol, Julien Siebert, Adam Trendowicz, Anna Maria Vollmer, and Stefan Wagner. Software engineering for ai-based systems: A survey. *ACM Trans. Softw. Eng. Methodol.*, 31(2), apr 2022.

[MKK+21] G. Mylonas, A. Kalogerias, G. Kalogerias, C. Anagnostopoulos, C. Alexakos, and L. Munoz. Digital twins from smart manufacturing to smart cities: A survey. *IEEE Access*, 9:143222–143249, 2021.

[NLA18] C. Ncube, S. L. Lim, and Amyot D., Maalej W., Ruhe G. On systems of systems engineering: A requirements engineering perspective and research agenda. *Proceedings - 2018 IEEE 26th International Requirements Engineering Conference, RE 2018*, 2018.

[PL20] Y.A. Prasetyo and M. Lubis. Smart city architecture development methodology (scadm): A meta-analysis using soa-ea and sos approach. *SAGE Open*, 10(2), 2020.
A Author contributions
Both authors contributed equally to the manuscript, the analysis and the interview process.

B Funding
This research was funded by the DynaSoS project (grant no. 01—S21104) of the German Federal Ministry of Education and Research (BMBF).

C Informed consent
Informed consent was obtained from all subjects involved in the interviews.

D Conflicts of interest
The authors declare no conflict of interest.