CONFERENCE PROCEEDINGS

Proceedings of the
Joint International Resilience Conference 2020
Interconnected: Resilience Innovations for Sustainable Development Goals

23 - 27 November, 2020

JOINT INTERNATIONAL RESILIENCE CONFERENCE
NOVEMBER 23 - 27, 2020
ONLINE

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(FRS) FUTURE RESILIENT SYSTEMS

PREFACE

The Joint International Resilience Conference, co-organized by the 4TU.Centre for Resilience Engineering and the Future Resilient Systems Program FRS at the Singapore ETH Center SEC, took place in November 2020. The conference brought – for the first time – together two communities that were before organized separately.

Conference as a meeting place
The 4TU.RE conferences and community focus on improving resilience of coupled socio-technical-environmental (STE) systems. Accordingly, resilience engineering knowledge and expertise are combined with principles of adaptation, both of which are learning and tipping points characteristic for the socio-ecological systems. FRS Singapore had organized two conferences on resilience preceding the current joint event.

The International Conference on Infrastructure Resilience in 2018 was initiated together with the ETH Risk Center and held in Zurich, Switzerland. In July 2019, FRS hosted the World Congress on Resilience, Reliability and Asset Management in Singapore, integrating the International Conference on Reliability Systems Engineering (organised by Beihang University), and the World Congress on Engineering Asset Management (organised by the International Society of Engineering Asset Management). Such events were held with the aim of enabling exchange about foundational concepts of resilience across domains as well as highlighting communalities and differences of resilience-oriented methodologies in different academic and real-world application areas.

As such, the conference sought to be a meeting place. And we are proud that we brought together more than **800** participants from four continents, working on different areas of resilience design, modeling, measuring & analysing and governance.

Sense of urgency
Overall, the conference was marked by a sense of urgency. Because of the Covid-19 pandemic, the conference had to take place online, illustrating the challenges of connecting and fostering (social) cohesion and community resilience, and the increasing divides and inequalities that we are facing. At the same time, urgent solutions for the climate crisis, the loss of biodiversity, and the need for sustainable food chains were high on the agenda. There was widespread consensus on the need to come together as a scientific community to urgently address the related challenges by new infrastructure and urban design using nature-based solutions and innovative engineering; leveraging the power of data and AI to improve monitoring and measuring; and to integrate the cognitive and social aspects of resilience that are vital in a time of fragmentation and unrest.

Key themes
These proceedings provide an overview of the submissions and key thoughts exchanged at the conference. In total, we received **63** submissions, from which **48** were selected for publications in the proceedings. All papers compiled in these proceedings underwent a thorough review process by the Session Chairs, and then by the Scientific Committee. The editorial team then compiled these conference proceedings, which can be divided into three parts.

Track A. on Designing resilient systems presents with **8** papers that are focused on the design challenges for coupled socio-technical-environmental systems. Topics discussed ranged from designing for resilience in agriculture, to co-creation for designing resilient cities. Key challenges discussed were how to design for an interconnected world with shifting values and fluctuating requirements. Further, there were vibrant discussions on how to bring together science and practice, given the urgency of many of the planning problems ahead.

For Track B., Modeling and Designing Interdependent STE-systems, the main focus was on agent-based modeling approaches, represented with **15** papers in the proceedings. The discussion evolved around how to capture and adequately model feedback across systems, spatial and temporal scales, and how to use ABM to understand the mechanisms and principles that are decisive for systems to quickly recover from disruptions. These mechanisms, in turn, then can be used as requirements to engineer for resilience.

Track C. Measuring and analysing resilience of interdependent STE systems brought together researchers from data analytics, machine learning and AI, with resilience thinking and decision-making under deep uncertainty, with a total of **11** papers in the proceedings. On the data & AI side, several novel approaches presented new ways to tap into the potential to use sensing systems to monitor resilience in real-time, opening up new research avenues especially for social resilience, asset management and maintenance. Of course, analyses only have an impact if they support decisions. Here, a crucial question is how to combine insights about deeply uncertain decisions with advances from resilience thinking, embracing complexity, tipping points and learning.

Track D. Governance systems and institutional arrangements for STE resilience with **13** papers featured sessions on governance and institutions, stakeholder involvement, and bottom-up versus top-down planning approaches. Here, key questions entailed capturing the plurality of voices and values, as well as developing governance arrangements that and foster long-term resilience thinking over short-term political gains. Further, the ethics perspective was prominently represented, with important research about morally sensitive design in a world with increasingly shifting values.

Track E. with **1** paper focused on the challenges for resilience brought about by the Covid-19 pandemics, and how, in turn, resilience methods and approaches can help improve the response to the current and future pandemics.

On behalf of the Conference Organizers and the Scientific Committee, we thank all authors and presenters who contributed to the proceedings and the vibrant discussions during the conference. A special thanks goes to the organizers of sessions and workshops and the reviewers. It certainly was not an easy task to adapt to the ever-changing circumstances, and we thank you all for your resilience. We hope that you will enjoy reading the proceedings and look forward to seeing you at the next resilience events and conferences.

Dr. Tina Comes
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DESIGNING RESILIENT SYSTEMS

TRACK A

Equitable Resilience: Uncovering Disparities in Societal Impacts of Infrastructure Service Disruptions

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Summary

This paper presents a human-centered approach to empirically analyze the relationships between households and critical infrastructure service disruptions by examining how the exposure and households' ability to withstand disruptions in various infrastructure services (e.g., transportation, power, water, and communication) would affect the well-being of different sub-population groups. The results concluded that racial and ethnic minorities, low-income groups, and households with young children experience greater hardship, and consequently, greater well-being impacts as a result of disruptions to critical infrastructure services during a disaster. A novel finding of the study, however, is the differential impact that service disruptions have on households according to household sociodemographic factors. The results from this analysis aim to emphasize the importance of including different community perspectives and needs in infrastructure resilience planning by providing empirical evidence of disparities in the societal impacts of infrastructure service disruptions.

Keywords

Infrastructure resilience; equitable resilience; social disparities; critical infrastructure

Introduction

Natural hazards place tremendous stress on critical infrastructure systems by testing their service reliability under extreme conditions (Mostafavi 2018). Prolonged service disruptions can pose serious threats to the physical, emotional, and mental well-being of residents in a community (Chang 2016; Yoon 2012). In fact, critical infrastructure such as transportation, power, water, and communication systems are vital to maintaining the structure of a community (Mostafavi et al. 2015; United Nations Office for Disaster Risk Reduction 2009). In the standard infrastructure resilience model (Figure 1), the goal is to eliminate the loss of service functions and improve the rapidity of function restoration in systems. However, this model fails to consider the variation in the sociodemographic characteristics of subpopulations and the extent to which vulnerable populations (e.g., low-income families and racial minorities) are disproportionately exposed to risks due to service disruptions. As a result, there is a lack of fundamental information about household interactions with infrastructure services in disasters, and more specifically, how these interactions differ with respect to different subpopulation groups. Understanding the disparities in infrastructure disruption impact is key to integrating the needs of diverse populations into planning and prioritization of resilient infrastructure while mitigating impacts to the most vulnerable members of society when infrastructure services are disrupted.

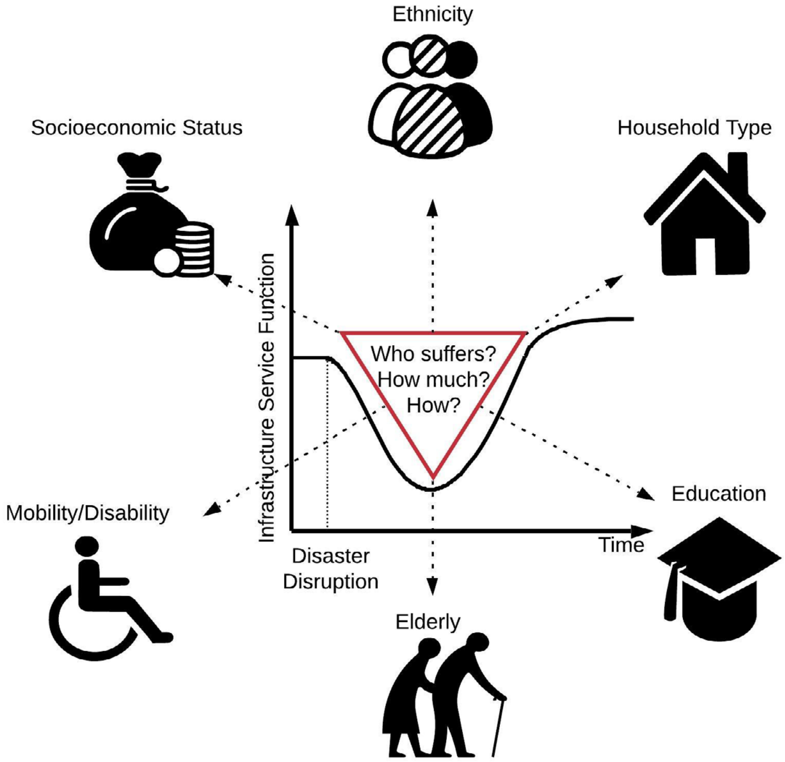

Figure 1: Equitable infrastructure resilience: integrating societal dimensions into standard infrastructure resilience framework

Therefore, our research study holistically views the disaster impact on individual households through four dimensions: the experienced hardship, the extent of exposure, the zone of tolerance, and the well-being impact. Specifically, our research aims to answer the following:

(1) To what extent are different social subpopulations impacted by different service disruptions? Are certain groups disproportionately affected?
(2) To what extent is the experienced hardship due to the extent of exposure compared to the zone of tolerance of subpopulations?
(3) Are there disparities among socially vulnerable subpopulations in terms of exposure to extended service disruptions as well as the zone of tolerance?
(4) Do infrastructure disruptions influence well-being impacts in households? If so, what services have the most impacts and on which well-being dimension?
(5) Are there disparities among households with vulnerable population groups in terms of well-being impacts caused by infrastructure service disruptions? If so, what sub-populations experience disproportionate well-being impacts for different service disruptions?

To address these questions, a new framework for a human-centric infrastructure service model that conceptualizes the association between humans (in terms of experienced hardship, the zone of tolerance, and well-being) and infrastructure (in terms of service provisions) is introduced. Secondly, an approach to determining disparities in well-being impact due to different service disruptions at the household level (Figure 2) is discussed and demonstrated using empirical data collected from a household survey collected from the affected communities in Harris County, Texas, and analyzed using correlation analysis.

Well-being impacts of the service disruptions on the households are the function of the hardship that households experience and whether they have the social capital to mitigate the risks on their well-being. However, not all households would experience equal hardship. Households depending on their sociodemographic characteristics, previous experience, and perceived risks have varying levels of tolerance for the services; they have different resources to take protective actions; they are not equally capable of withstanding the disruptions. Therefore, disparities exist as a result of the sociodemographic characteristics of the households lead to unequal societal impacts when the natural hazards cause disruptions in the infrastructure services.

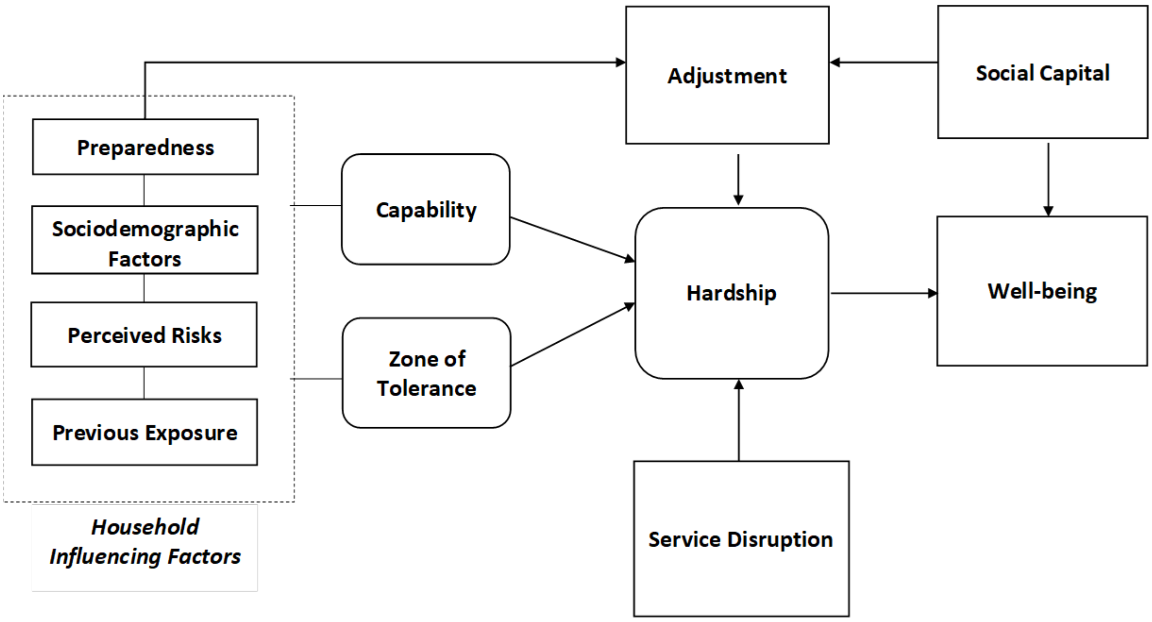

Figure 2: "Infrastructure-Wellbeing" Framework

Results

The empirical analysis of the survey data revealed that households with a social vulnerability have a significantly lower tolerance for the disruptions in the infrastructure services. In addition, these households may live in areas where it is more probable to experience prolonged disruptions in the services (Figure 3). They also have lower resources and capabilities to prevent or mitigate the risks. Therefore, they experience higher hardship and, consequently, a higher well-being impact, as shown in Figure 4. The significant association of the service disruptions with the well-being impact and the stronger influence on the socially vulnerable populations provides the evidence that the current practice of designing the infrastructure service does not lead to an equitable resilience for all and calls for improvements in how the performance objectives are defined.

Designing resilient STE systems
Achieving Social Impact Through Visual Smart Planning

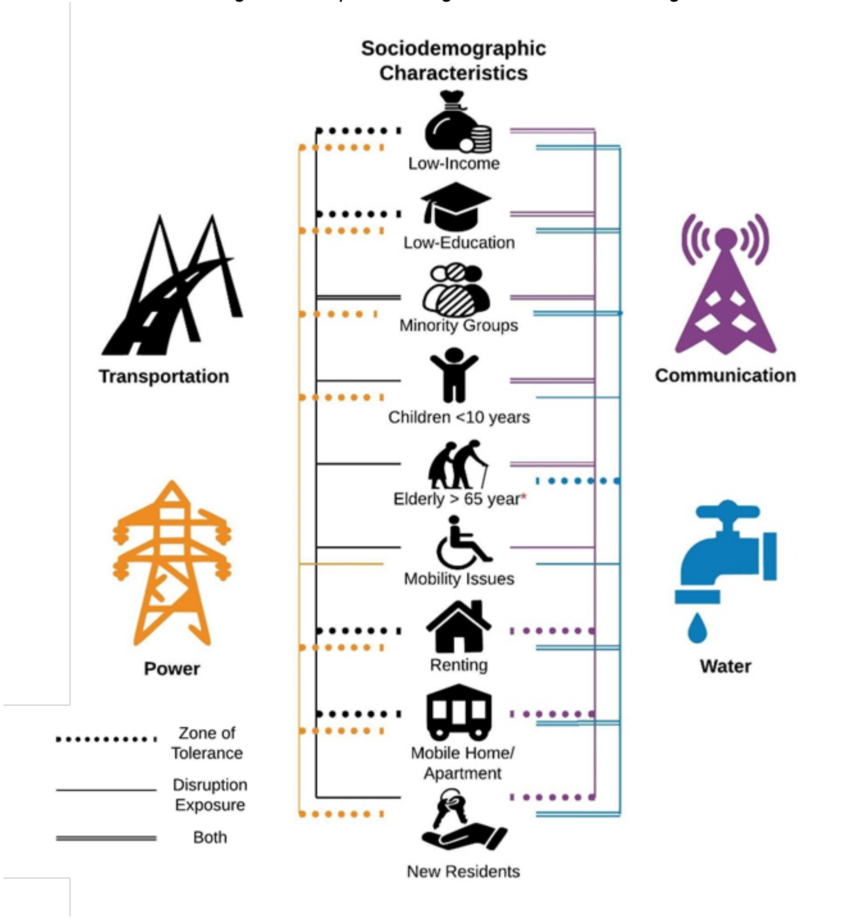

Figure 3: Disparities in Exposure and Zone of Tolerance to Infrastructure Service Disruptions of Households in Harris County during Hurricane Harvey. Solid lines indicate the disparity in the experienced duration of the disruptions. The dotted lines indicate the disparities in the zone of tolerance of the households to the service disruptions, and double lines display the condition where both duration and zone of tolerance are significant for the sociodemographic characteristics. Important note that elderly residents experience a lower period of disruption and greater zone of tolerance.

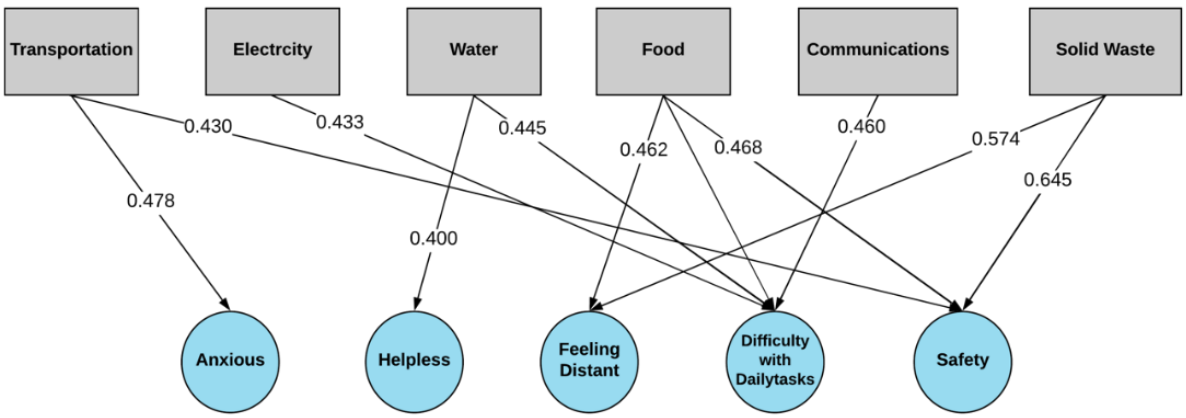

Figure 4: The Characterization of Service Disruptions by Average Spearman's Rho and Most Frequently Associated Well-being Dimension According to All Subgroup Populations. Service disruptions are frequently associated with difficulty with daily tasks, followed by Safety and Feeling Distant. Well-being dimensions "Depressed" and feeling "Upset" did not appear to be associated frequently with infrastructure disruptions.

Conclusion

This study advances the understanding of social inequalities in hardship experienced and exposure due to infrastructure service disruptions in disasters. In particular, the findings provide the much-needed empirical information necessary to uncover the extent to which subpopulations in a community experience varying levels of the disaster impact due to infrastructure system disruptions. Hence, the study contributes to establishing the fundamental knowledge needed for a paradigm shift towards a more equitable resilience approach in infrastructure systems. The results of this study have concluded that not only do certain socially vulnerable subpopulations experience disproportionate impacts due to infrastructure service disruptions in general, but also the type of infrastructure service and the well-being impacts are different too. These results have demonstrated the importance of integrating both physical and social vulnerabilities into a human-centric infrastructure resilience model. Our findings indicate that certain socially vulnerable subpopulations have unique needs and expectations from each infrastructure service, all of which must be factored into an equitable resilience model.

Acknowledgements

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Migration patterns of multiple urban redevelopment: An agent based spatial microsimulation[1]

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Summary

This lecture presents the outcome of applied research regarding the failure, thus far, to incorporate the social implications of planning and development into the urban planning process. In response to this failure, we propose the use of microsimulation to assess the social impact of urban redevelopment. The microsimulation approach enabled us to not only engage in characterizing and analyzing the social and spatial environment, but also to consider the individual or, in this case, the household, as an active agent. To generate the simulation framework, we chose to define the conditions of the the city of Bat Yam – one focal point of urban redevelopment in Israel - and the agents via the lens of economic logic. The simulation highlights the migration patterns resulting from urban redevelopment, as well as its impact on the sociological profile of the city. Specifically, it shows a clear trend of transformation in agent-income composition.

Keywords

urban redevelopment, gentrification, displacement, spatial microsimulation, agent-based model, Israel.

Introduction

Around the world, cities and urbanism are expanding at such a rapid pace that we can speak of a “second urban revolution” (Portugali, 2006: 9). This revolution is taking place concurrently with the formulation of a new science of cities (Batty, 2010). In recent decades, an understanding of the complexity of biological and ecological systems has contributed to the discussion of the complexity of cities (Portugali et al., 2012), to contemporary research on urban cognition (Sengupta et al., 2016; Zellner & Campbell, 2015), as well as alternative and adaptive urban planning models (Skrimizea et al., 2019). This field has developed model-based tools to examine social issues in the urban arena.

Here, we join this effort by proposing an applied tool for examining the impact of urban redevelopment in a realistic environment. To this end, we have developed a spatial microsimulation that systematically models migration patterns on the individual building scale. The purpose of our study is twofold: first, to enhance social impact assessment by importing advanced spatial modeling tools – specifically, Agent-Based Spatial Microsimulation; and second, to contribute to the field of spatial simulation by creating a realistic modeling tool based on a particular site and detailed data at the household level (as opposed to the level of the statistical area alone). In doing so, we hope to nudge spatial simulation toward the environment of urban planning and to help further develop its ability to contend with social issues, and particularly with the phenomenon of urban migration shaped by urban redevelopment.

Many studies that address the topic of urban migration report displacement as a consequence of gentrification (Marcuse, 1986). Grier and Grier’s (1978) classic definition describes population displacement as what occurs when householders are forced to move out of their place of residence as a result of conditions affecting the immediate environment. Displacement may occur as a result of investment in the neighborhood that increases rents and apartment values. In such situations, not only are apartment tenants forced out, but apartment owners also sell their apartments and leave (Eckerd, Kim & Campbell, 2019; Chapple, 2014).

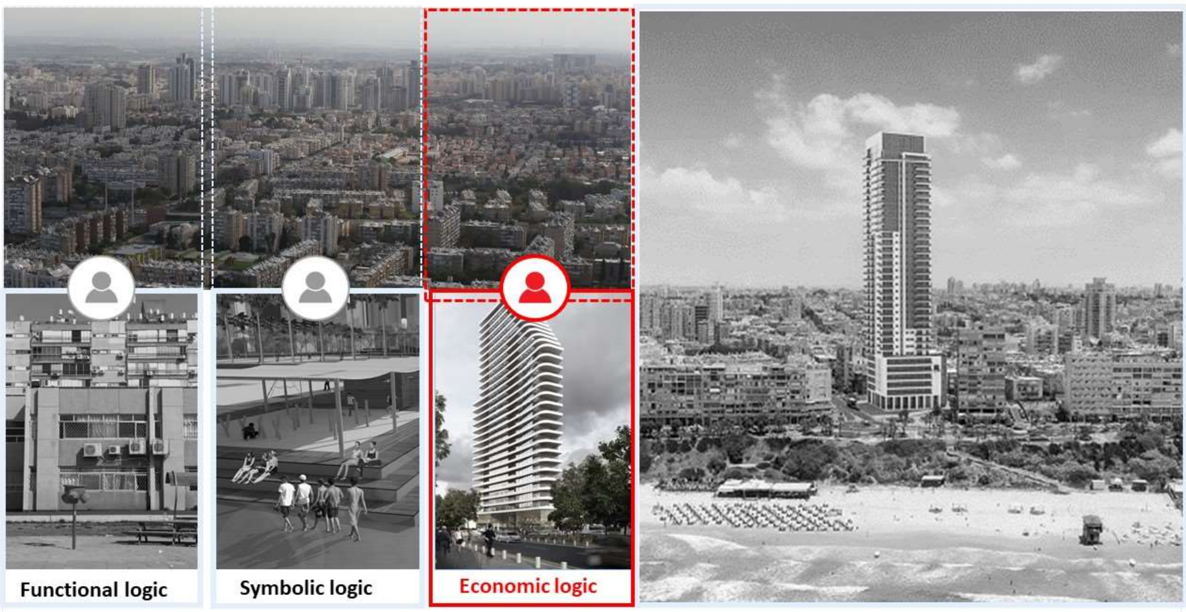
[1] This article was submitted to a journal and is currently under review.

We seek to highlight the phenomenon of gentrification-based displacement in the context of urban redevelopment and to assess the resulting patterns of urban migration. We do so by taking into account both the households impacted by redevelopment and the conditions within which they act.

In social theory, the role of the individual agent is constantly debated. Classical sociological theories range from those that perceive social structure as imposed on the individual (e.g., Marxist theories) to those that view the social subject as an agent. At the core of every societal issue, like that of immigration, lies the question of how much power the social structure has over the individuals, and whether they are active agents or victims of the circumstances. Underlying this lecture is an attempt to give expression to this theoretical tension. A micro-model allows us both to define the change in conditions and to relate to households as agents with the ability to act in different ways. We took an interest in the method of agent-based modeling (ABM) since we regarded it as an exercise that touches the core of sociological theory: the tension between social structure and agents.

To generate the framework for this research, we sought to conceptualize the definition of urban conditions and the definition of agents. We started by asking: What are the forces that push people out of their buildings in the context of urban redevelopment? In the social and urban sciences, we identified three logics underlying population displacement. The first is functional logic, according to which people feel that spatial function has been disrupted – for example, that the house of prayer that you use to go - has closed. These changes preclude them from using the neighborhood as they previously had or attracted new people to the neighborhood who seek proximity to spatial amenities (Boeing, 2018). The second is symbolic logic, according to which a change in population causes people to feel that they no longer share the same meaning for the (new) socio-urban construction (Campbell, Kim, & Eckerd, 2015; Eckerd, Kim, & Campbell, 2019). The third is economic logic, according to which the economic burden play a major role in people decision whether to leave or stay under new economic conditions such as cost of maintaining buildings, the cost of living in the neighborhood, and the profit generated by the apartment undergo change (see Figure 1).

Each of these interpretive frameworks involves a different social agent. The first consists of the homo functional – that is, the person whose function is at the forefront of his or her mind. The second emphasizes the meaning of Clifford Geertz's (1973) homo symbolicus. Finally, the third involves the homo economicus, who calculates considerations of profit and benefit for his or her household. In this lecture, we focus on the third type by formulating definitions of urban conditions that are based on economic logic and by characterizing the household accordingly.



a. Theoretical framework and its application to the case study - the city of Bat Yam

b. Visualization of ("Dream Tower" project) one of many planed in the research area

Figure 1. The lenses for the social analysis of urban migration and the three urban types

It should be emphasized that we do not expect the simulation to produce an accurate prediction of migration for cases of urban redevelopment. A city is a complex place, and the system of variables and mutual influences is extensive and difficult to predict. We expect the simulation to provide us with probabilities of several indicators regarding the physical and social dynamic in the city on the condition that its current structure remains stable (Portugali, 2006). In this way, we are responding to the lack of tools for incorporating social aspects into processes of spatial policy formation. We, therefore, propose viewing the simulation as a means of generating a data-based discussion among planners, policymakers, and academic scholars (Levy, Martens, & Van der Heijden, 2016), and we hope that this investment will result in bringing the sociological effects of the urban processes to the forefront of public attention.

In order to further develop the sociological tool used by the urban redevelopment processes, we demonstrate our simulation in an urban arena within a neighborhood in the Israeli city of Bat Yam (Figure 2). Bat Yam is at a pinnacle of urban redevelopment vis-à-vis its population size. By May 2019, approximately 8,800 apartments had been approved in "raze and rebuild" plans (that we will present in detail later), which, in Israel, is a figure second only to Tel-Aviv (10,600 apartments), despite the fact that Bat Yam's population is 40% smaller (Calcalist, 2019). The approved plans in Bat Yam are only the initial step in a massive wave of urban redevelopment encompassing approximately 18,000 additional planned apartments.

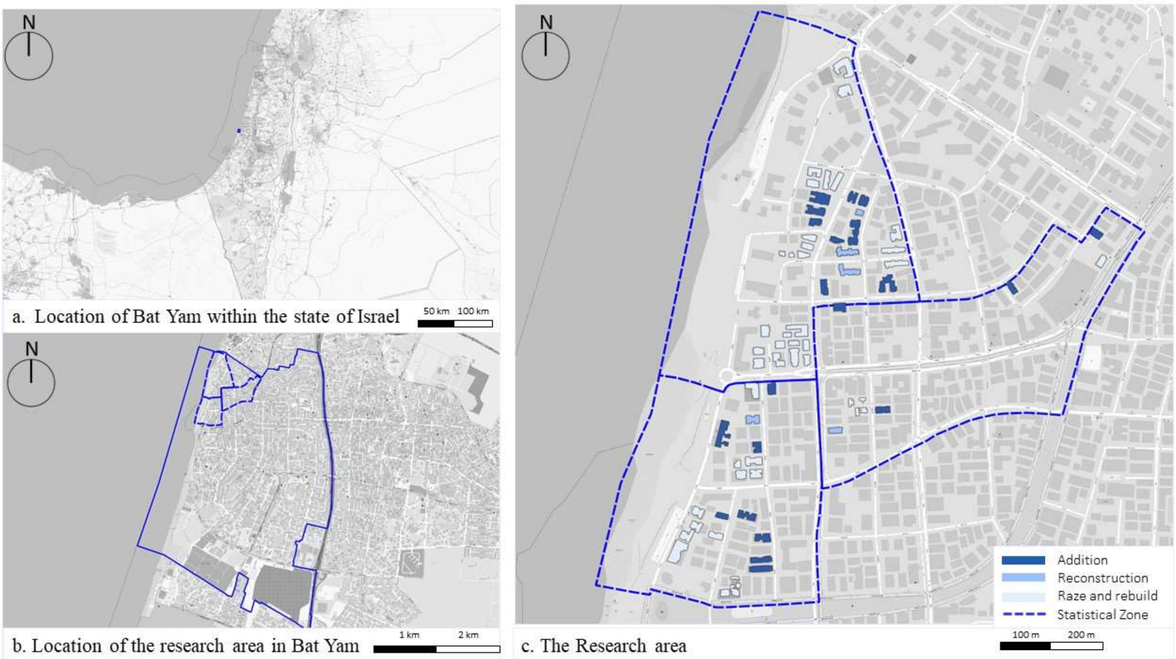


Figure 2. The Research area

The major challenge of our undertaking is to produce a realistic agent-based spatial microsimulation that represents different aspects of the migration patterns that follow these phenomena. In this lecture, we present our research area and methodological approach, which is based on variability in the economic conditions and consideration of the built environment. We have cross-referenced the economical-physical aspects of the redevelopment environment with an array of characteristics of the agents. Furthermore, we highlight these interactions and relationships based on assumption and decision trees that we constructed. Finally, we present the results: an array of statistical figures regarding the migration dynamics of the variety of agents involved in urban redevelopment of the research area.

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A support system for identifying changes in infrastructures during disruption scenarios

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Keywords
Visual support; resilience; decision making

Providing necessary supplies in a crisis situation heavily relies on prior knowledge of fast and reliable travel routes in the road infrastructures. In case of a natural disaster, however, parts of the infrastructure could be destroyed which leads to certain roads and crossings being used more frequently than before.

Therefore, an interactive application allowing to detect changes in important crossings after parts of the network have been destroyed has been developed. A modified betweenness centrality [1] is applied for measuring the relevance of a crossing with respect to a certain target. Recognizing several successive states of individual crossings is enabled by a glyph visualization. Thus, important areas for reaching a particular target (e.g., a hospital) can be identified and changes over time as destruction increases can be analyzed. Simultaneously, the glyphs support comparing the importance of different areas with respect to different targets, as a certain area might be of interest for only one of them.

The proposed tool shows the users already calculated betweenness centrality measures and lets them calculate new ones with a random disruption simulation. It provides a focus and context visualization supporting the users analyzing areas in more detail while maintaining spatial reference to the remaining structure. Geometric and semantic zooming as well as panning is provided. The semantic zoom entails a removal of structures with dead ends or structures being connectors between

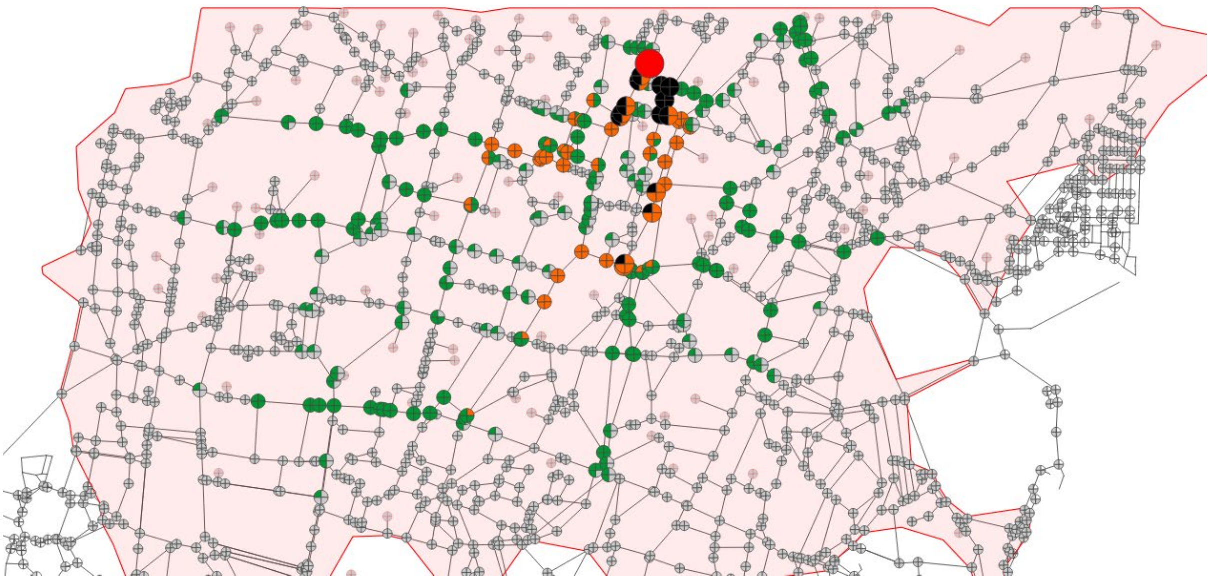

Figure 1: An example of the results from the proposed application using a part of a selected study area – the city of Kathmandu in Nepal.

two crossings. A force-directed-layout can be applied to move the glyphs further apart and therefore reduce overlapping.

Ultimately, the application aims assisting planning and decision making process in disaster management.

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Multi-Level Resilience: Community initiatives and individual behavior

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Summary
The multi-level nature of resilience is frequently discussed conceptually, yet often ignored in empirical analysis. Additionally, due to data collection and scaling challenges, private adaptation is rarely considered in larger scale resilience analysis'. We use household survey data and data from a community program designed to promote community flood preparedness/ private flood insurance, to explore the influence a community level initiative can have on individual behavior. We find that different mediums of information transmission can have different effects, contingent upon the community in which the respondent resides.

Keywords
Multi-level Resilience; Flooding adaptation; Survey; NFIP

Introduction
Resilience to natural hazards, when empirically quantified, is typically assessed with population and regional summary statistics used to approximate and compare system resilience at distinct levels (Cai et al. 2018). The results depend on the variables selected and on the scale at which measurements are taken (Cutter and Derakhshan 2019). While these findings offer good context, they regularly ignore a critical component of disaster resilience - private action - and its role in cross-scale climate change adaptation (Adger et al., 2005; Filatova 2014).

Empirical resilience assessments often suffer from a single-level focus, while conceptually the resilience literature recognizes the importance of feedback between levels and in particular, individual level action. Initiatives like Flood Resilience Measurement for Communities by the Zurich Flood Resilience Alliance (Keating et al. 2017) aim to bridge this gap but the complexity and specificity of ratings used in analysis makes generalizations difficult. This paper addresses this gap while focusing on resilience and private climate change adaptation to one of the costliest disasters worldwide: flooding (Aerts et al. 2014). We use results from a large household survey aimed at better understanding household perceptions and behavior toward flooding and combine it with the US FEMA data regarding community involvement in the National Flood Insurance Program (NFIP). We explore the effects of the NFIP - one of the US government's most prominent programs aimed at increasing flood resilience - on influencing behavior and perceptions at the household level.

Background
In March 2020, as part of a larger international longitudinal survey, we surveyed about 2000 respondents living in three of the most flood-prone states in the United States: Florida, Louisiana, and Texas. The primary objective of the survey is to better understand individual behavior under risk of floods, individual socio-economic resilience and to explore factors that lead to private climate change adaptation in coastal cities. Despite having data from several other countries, here we elect to focus solely on the USA as it allows us to explicitly explore an under-researched aspect of resilience: multi-level-feedbacks. We explore commonalities and differences in individual adaptation behavior through a community level program: Community participation in the NFIP. The United States Federal Government instituted the NFIP more than 50 years ago to share risks, raise flood risk awareness and motivate communities to be better prepared for floods (Lave and Lave, 1991). The NFIP aims to strengthen communities' flood preparedness by mandating a community undertake a number of governance related requirements including a flood emergency plan and flood ordinances. Once a community qualifies for membership, the NFIP actively encourages residents of member communities to purchase subsidized flood insurance.

Methods
The NFIP offers an ideal test case to explore the effect of a government-supported community level initiative on individual behavior. While multi-level resilience research has been conducted before in the USA with governmental flood initiatives (e.g. Brody et al. 2017), previously the number of communities was very limited. With respondents living in more than 200 unique communities not participating in the NFIP (n>700), and more than 300 unique communities participating in the NFIP (n>1000) our dataset offers a novel look into the effect of a community initiative on the perceptions and behavior of households.

To conduct the analysis, we utilize Bayesian statistical methods, namely: the Bayesian T-test to look for differences between households living in NFIP participating communities vs. those not and Bayesian hierarchical logit models to explore differences in effects between the two types of communities. In our analysis we focus primarily on Flood Insurance as an adaptive action. As one of the primary goals of the NFIP, private insurance is understood to play an important role in climate resilience (Surminski, 2016). To explain individual intention to purchase flood insurance, in addition to the multi-level variable (community participation in NFIP), we use an expanded version of Protection Motivation Theory (PMT) (Grothmann and Patt 2005) (Figure 1).

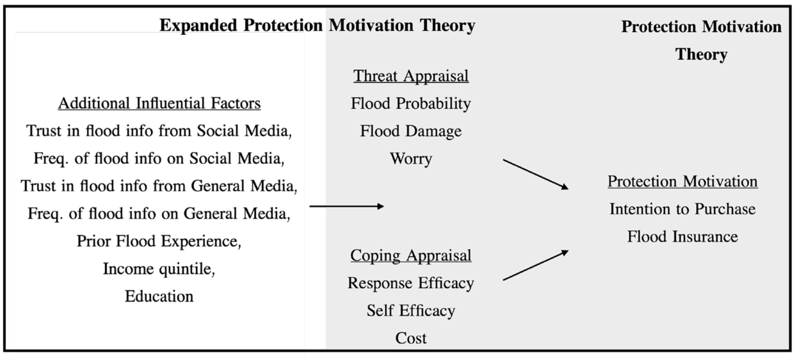

Figure 1: List the variables included in our analysis of individual intention to purchase flood insurance.

Results
Research has shown that private flood insurance can be foster resilience (Aerts, 2011). There is limited research however on how it impacts individual sentiments. In our survey we asked respondents to self-assess their own resilience using six different (1-5) Likert scale questions designed to represent different facets of the construct (Jones, 2019). When comparing the self-assessed resilience scores for respondents that had flood insurance vs. those who did not, insured respondents on average ranked themselves 5% higher than their un-insured counterparts; a 100% likely difference according to the Bayesian T-Test. This finding supports the notion that flood insurance not only has the potential to foster resilience at the societal level (Surminski, 2016), but at the individual as well. Thus, supporting our focus on the NFIP, a program designed to support community preparation and encourage the uptake of private flood insurance. While the program has faced criticism on efficacy (Aerts, 2011), it's objectives address flood risk at multiple levels. Below we look at the effects that living in a NFIP participating community has on respondents.

Using the Bayesisan T-Test, we look for differences in means and distributions between respondents living in NFIP communities and those not. We do not find any meaningful difference in either prior insurance purchase or intended insurance purchase - one of the primary goals of the NFIP - among the respondents residing in participating and non-participating communities. We do however find likely (>99.5%) differences in the frequency that residents hear about flooding and other natural hazards from both the general media and on social media (Figure 2). Information frequency has been shown to be important for taking an adaptation action, especially with rare events (McEwen et al. 2017). Furthermore, risk communication is one of the NFIP's goals. Respondents living in communities belonging to NFIP also self-reported greater social expectations from their friends and neighbors to take action toward flooding.

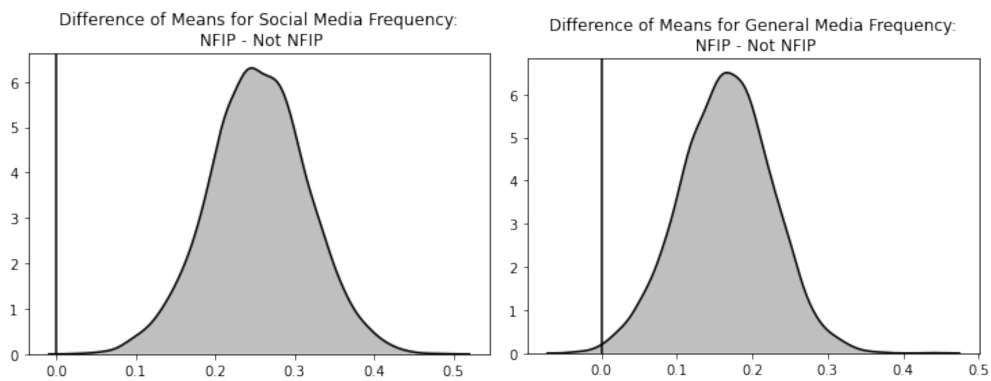

Figure 2: Differences in means of Social media frequency (left panel) and General media frequency (right panel) for those living in a NFIP community vs. those who do not. These variables are generated from a Likert scale of 1-5.

After exploring the differences in means, we search for any differences in effects that are present. We run several Bayesian nested logit models with 'intention' to take different adaptation actions as the dependent variable, using broad normal priors in all cases. When modeling intention to take flood insurance, a primary objective of NFIP, we note several differences in effects. With two media variables: Trust in Media and Trust in Social Media when it comes to information about disasters and flooding (Fig 3).

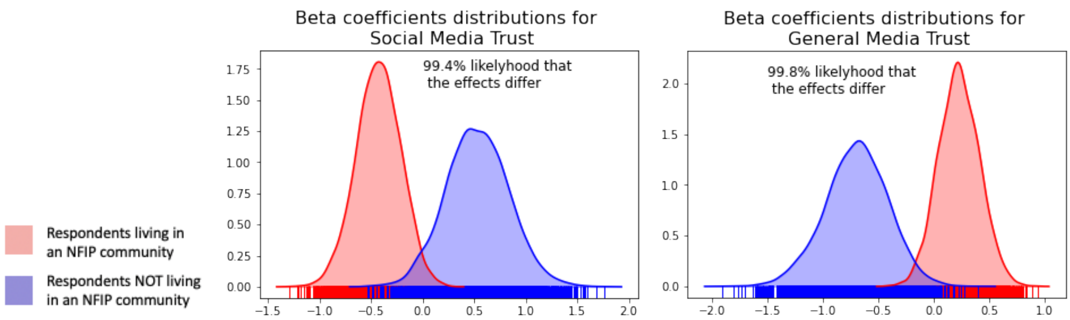

Figure 3: In both cases living in a NFIP participating community is the reference variable for explaining intention to take insurance. We subtracted the respective beta coefficients of respondents not living in an NFIP participating community from those who do to get the distribution of the differences of means.

Discussion

In using the Bayesian T-Test to test differences of means we found meaningful differences in the means of several factors regularly used to estimate individual protection motivation. In NFIP communities, respondents report seeing news about flooding and other natural hazards in greater frequency than then those not. As flood information transmission is a goal of the NFIP, these likely differences, in addition to the others, suggest that the NFIP likely has marked influence at the individual level.

Secondly, in looking into differences of effects, we see that social media trust and general media trust differ in their effect depending on if the respondent lives in an NFIP community or not. We theorize that NFIP communities are likely more active in promoting flood related policies and information, thus respondents in these communities rely less on social media, and more on information through more traditional media channels. Therefore, despite trusting social media more than those living outside NFIP participating communities, respondents living in an NFIP community are generally more influenced by trust in the general media in their decision to take out flood insurance. In an era where fake news is becoming more prevalent and there is an almost infinite amount of information on the internet about any given topic, trust and response to official information is an important component of resilience.

Conclusion

With climate change escalating flood risks, more traditional 'upper level' actions on their own, not sufficient to meet the new flood reality many communities face (Filatova 2014, Blöschl et al. 2020). Robust community resilience demands that private action complement more traditional 'upper level' community measures. In this analysis, we utilized data from two levels (the community and the individual) to offer a more complete picture of resilience in our study regions. Our findings suggest that while insurance uptake does not meaningfully differ between communities participating in the NFIP vs. those not, there are some other indications that suggest NFIP participation does contribute to resilience. These differences offer empirical support for the importance in considering the multi-level nature of resilience - a marked hole in the existing empirical literature. With the increase in data availability online we hope this analysis inspires future work to further explore multi-level feedbacks when studying complex systems.

Acknowledgements
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The effect of climate change on flood risk perception: a case study of the Grensmaas using a coupled hydraulic & agent-based model

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Summary

Due to climate change and a growth in population and assets, flood risk is expected to increase in the future. In this study, we aim to set up a coupled hydraulic & agent-based model that predicts changes in locations and climate adaptation choices of heterogeneous households. Detailed flood maps are created with a hydraulic model to increase the reliability of the outcomes of the agent-based model. The Grensmaas area in the Netherlands, serves as a case study. In this abstract, we describe our intended methodology. The outcomes of this study will help decision makers with establishing proper flood management strategies by identifying the most vulnerable areas in terms of economic damage.

Keywords

Flood risk; hydraulic model; agent-based model; flood hazard maps; flood perception

Introduction

Floods are considered as one of the main hazards causing tremendous damage and life-loss worldwide (UNISDR, 2013; OECD, 2016). The annual flood losses in Europe are expected to increase fivefold by 2050 (EEA, 2016). This increase is caused by two factors. Firstly, it is expected that the flood intensity and the flood frequency increase due to the impact of climate change (Bomers et al., 2019a; Hirabayashi et al., 2013; Arnell and Gosling, 2016; Alfieri et al., 2017). Furthermore, flood risk increases due to the growth of population and assets; the wealth of societies grows in or close to historic cities which are often located along rivers and deltas (Brádzil et al., 2006). More specifically, for the Meuse river in the Netherlands, the discharge corresponding to a return period of 1,250 is expected to increase from 3,800 m^3/s in 2001 to 4,550 m^3/s in 2100 (De Wit et al., 2008). This significant growth in the design discharge increases the need for proper flood management strategies. However, if discharges keep increasing in the future, flood risk cannot solely be mitigated by managing the strength and height of the flood defences. Also, the potential consequences in terms of flood damages and urbanization in floodplains should be managed. To prioritise between various vulnerable areas, two aspects are highly important. Firstly, detailed hydraulic models are required to simulate the flow patterns, inundation extent and water levels during the flood (O'Shea et al., 2019). Secondly, the socio-economic response in terms of changes in values at risk, shaped by patterns of construction development and housing prices, and climate change adaptation actions in terms of e.g. flood reduction measures should be studied.

In this study, we aim to set up a coupled hydraulic & agent-based model to get a better picture of the consequences of potential future flood events. A detailed hydraulic model is used to compute flow patterns and inundation extents during various flood events (Apel et al., 2016; Bomers et al., 2019b; Pasquier et al., 2019). The output of this model serves as the input of the spatial urban agent-based model, which traces location and adaptation choices of heterogeneous households that vary in incomes, risk perceptions and behavioral heuristics (Filatova et al., 2011; de Koning and Filatova, 2020). The insights of these models will help decision makers with establishing proper flood management strategies by identifying the most vulnerable areas in terms of economic damage.

Case study

The river trajectory Grensmaas in the Netherlands is used as a case study. The Grensmaas is part of the Meuse river and located close to the Belgium-Dutch border. The Meuse river is a rain-dominated river which originates in France and flows through Wallonia, Belgium, to the Netherlands at Eijsden. Floods generally occur during the winter months due to a combination of saturated soils due to long-term rainfall, low evaporation and snow melt (Yossef et al., 2018). In 1993 and 1995 the water levels in the Meuse river were extraordinary high leading to economic losses and new flood protection measures, which fell under the Room for River program. Yet, the initial increase in flood risk perceptions among the inhabitants of the Grensmaas area and the way they have been living with recurring floods earlier, have been altered by the interventions. It raises questions on how flood-defense nature based solutions affect flood risk perceptions and capital at stake, and how benefits and risks of these measures are distributed. Since it is expected that the probabilities of occurrence of these events increase in the near future (De Wit et al., 2008), this study focusses on evaluating the effect of climate change in the Grensmaas area.

Methods

A hydraulic one dimensional-two dimensional (1D-2D) coupled model will be developed for the study area. In this model, the main channel and floodplains are schematized by 1D profiles while the hinterland is discretized on a 2D grid. Discharge waves are used as upstream boundary conditions whereas discharge-water level relations are used as the downstream boundary conditions. The hydraulic model is calibrated with the 1995 flood event by altering the friction coefficients in the river until simulated water levels are close to measurements (Warmink et al., 2007). The 1993 flood event is used for model validation.

To assess the effect of climate change on flood risk perception, the method adopted here broadly comprises four steps:

(a) A 1D-2D coupled model will be used in a Monte Carlo framework to determine flood peaks in the Grensmaas area for the present-day and future climate scenarios (2050, 2100). The uncertain parameters that are considered, include the upstream discharge, the critical water levels indicating when the flood defences will fail, and the bed friction of the main channel (Bomers et al., 2019c). The future 2050 and 2100 simulations are performed by probabilistically assigning a change in discharge to the present-day discharge based on projected relative changes in upstream river flow.

(b) A flood frequency analysis will be performed to determine flood peaks corresponding to a range of return periods for both present-day and future conditions, see e.g. Bomers et al. (2019a).

(c) Hydraulic simulations are performed with peak discharges corresponding to several return periods based on the flood frequency analysis performed in the previous step. This results in flood hazard maps for present-day and future climate scenarios for various return periods. These maps serve as the input data of the agent-based model in the next step.

(d) A spatial agent-based model (Figure 1; Lee et al, 2015) will be utilized to analyze changes in location and climate adaptation choices of heterogeneous households based on the flood hazard maps obtained for both the current and future climate scenarios. To specify the households' behavioral rules, we will rely on social surveys grounded in the psychological theories of decisions under risk. Furthermore, we plan to integrate modeling of individual adaptation choices with the computational agent-based housing market model (Filatova, 2015; de Koning & Filatova, 2020). By focusing on the redistribution of risks across various socio-economic groups, we aim to quantitatively study socio-economic resilience to floods in light of the introduction of nature based flood-defense solutions and flood hazards increasing with climate change.

Figure 1: An example of changes in values at risk over time driven by socio-economic response to floods. The red colored areas indicate falling housing prices, the blue colored areas indicate increasing housing prices as individual preferences for location change in the agent-based model. Source: own simulations.

In this study, we only consider the one-way effects of flood events on socio-economic resilience without accounting for the opposite effect. The effects of e.g. building new houses and implementing reduction measures on flood hazard, as was done by Abebe et al. (2019), is recommended for future research.

Conclusions

This study presents a framework to couple a hydraulic and an agent-based model to predict changes in locations and climate adaptation choices of heterogeneous households in the Grensmaas area, the Netherlands, in the future based on the changes in flood hazards in the study area due to the effect of climate change, and social surveys. At the conference we will present initial ideas and model prototypes. We would like to discuss the next steps, potential challenges and ways forward.

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Development of an Innovative Price Risk Management Instrument in the Belgian-Dutch Pear Market

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Summary

This paper describes the development of an exchange-like swap trading platform in the Belgian-Dutch pear market. This instrument is highly innovative as it combines advantages of exchange traded derivatives (like futures) with those of over-the-counter price swaps. By arranging price swaps at the level of a farmers collective, the instrument is easily accessible for individual farmers. It is the first instrument that allows pear farmers to hedge against price risk using financial derivatives, and has potential for application to other agricultural commodities for which no financial derivatives are yet available. By describing key properties of the swap contracts and trading platform used, this paper helps to understand how exchange-like swap trading platforms can be successfully developed in other agricultural markets.

risk management; futures; price swap; price volatility; collective action

Introduction

Policymakers have been advocating and stimulating the use of risk management instruments in EU agriculture, following the Common Agricultural Policy's shift from managed to unmanaged markets during the last decades (Veerman et al. 2016; Michels, Möllman and Musshoff, 2019). One of the advocated solutions for managing price risk is the use of financial derivatives, which allow farmers to manage risk without interfering with production and marketing activities (Kang & Mahajan, 2006). Among the financial derivatives used in agriculture, futures have by far received the most attention. Futures markets are considered beneficial as they provide an anonymous market of derivatives, allowing farmers to manage price risk without incurring counterparty risk, and assisting in the price discovery process in commodity markets.

However, not all commodities are suitable for futures trading. Most of the commodity futures contracts that have been introduced have failed because of insufficient market depth or liquidity (Bergfjord, 2007). It is thus useful to examine whether other financial derivatives can help to manage price risk when futures markets are absent or their adoption is limited. Contrary to futures, which are standardized contracts traded on exchanges, price swaps (or "swaps") are bilateral contracts, traded over-the-counter (OTC). Swaps are contracts between two parties to exchange a variable price against a fixed price. Swaps are widely used in the oil market, but much less in the agricultural sector. Among the few examples are the pig and milk price swaps recently established in France and the UK (Cordier, 2018). In the BeNeLux, swaps have been introduced in agriculture in 2017, when a price swap between Belgian pig producers and a meat processing company was established (Vilt 2017).

While trading contracts OTC does not require farmers to be knowledgeable about derivatives markets, it has some inherent disadvantages. OTC markets are not transparent, and hence do not contribute to price discovery. Furthermore, OTC swaps disclose the identity of hedgers, thereby revealing strategic information, and create counterparty risk. This paper describes an innovative exchange-like swap contract trading platform that tries to combine advantages of OTC swaps with exchange-based hedging instruments. The platform enables swap trading between a cooperative, grouping Belgian and Dutch pear farmers, and pear buyers, in a similar way as futures contracts are traded on exchanges. Both pear farmers and buyers can thus anonymously engage in price swaps, without being exposed to counterparty risk, which is shifted to the collective level. By mimicking the bidding mechanism of exchanges, the system reveals the cooperatives' and buyers' future price expectations, and thus contributes to market transparency.

Key properties of the innovative swap trading platform

The swap trading platform developed by marketing consultancy firm DLV[1] serves to trade pear price swap contracts between The Fruit Trading Company (FTC), a farmers' cooperative, and pear buyers. To participate in swaps, farmers join the cooperative and subscribe a certain share of their production for hedging. Based on the aggregated quantity of pears subscribed, FTC concludes swap contracts with pear buyers. Upon expiry of a swap contract, differences between the fixed price and reference market price are cash settled between FTC and buyers. The overall gain or loss for FTC is offset by cash settlement between FTC and its members, proportionally to each members' share in the quantity covered by the swap. FTC's means of operation are paid for by a commission of €1 cent per kg contracted (i.e. 1.5% to 2.5% of the pear price), paid by farmers.

FTC's exchange-like trading platform provides an anonymous market for swap contracts. The identity of buyers is only known to FTC, as is the quantity hedged by members. Farmers and buyers can thus engage in price swaps without revealing information to their trading partners in the physical pear market. Following the first year, FTC developed a new trading platform that uses bids and asks (i.e., bid and ask prices) and bid sizes and ask sizes (i.e., quantities of contracts), similar to exchanges for futures and options. Contracts now cover periods of 2-3 months, and can be offered as bids or asks on the platform from one year upfront the contract period until its starting date. The platform hence reveals farmers' and buyers' expectations of pear prices for the coming year, and thus contributes to price discovery in the pear market.

As swaps are agreed between FTC, the cooperative, and buyers, counterparty risk (i.e., the risk that buyers or farmers would default on the cash settlement) is shifted to the collective level. In turn, FTC shifts this counterparty risk to a bank that provides a guarantee of EUR 0.15 per kg for all participating farmers. FTC protects itself from this risk by requiring members and buyers to make a deposit, or provide a bank guarantee, of EUR 0.15 per kg contracted. This guarantee is expected to cover the amount needed for cash settlement in all but extreme cases. Members may provide bank guarantees issued by their own lenders, but can also rely on general agreement between FTC and a Belgian bank. This bank provides the guarantee for all FTC members, and will seek to reclaim this amount on members in case they default on the cash settlement. As FTC is protected from counterparty risk, it is unlikely that it would default on cash settlement towards buyers.

Conclusion

This paper describes the development of an exchange-like swap trading platform in the Belgian-Dutch pear market. The platform tries to combine advantages of exchange traded derivatives (like futures) with those of price swaps, which are relatively simple to use and understand. Swap trading platforms may provide valuable risk management instruments when the requirements for successful use of futures markets are not fulfilled, such as in fruits and vegetables markets.

After one year of trading contracts, FTC's instrument appears successful in enabling price risk management and facilitating price discovery. However, further experience has to reveal whether it remains successful if conditions change in the Belgian-Dutch pear market. FTC's first year was one of unusually high pear prices, which may have pushed buyers to engage in price swaps. Nevertheless, the swap trading platform is perceived as a promising instrument. Expansion to swap contracts for different vegetables in the BeNeLux is already being examined. The platform is thus a pertinent case of innovation in risk management, that may inspire the development of similar instruments in EU - farming systems.

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Assessing climate resilience of semiarid farming systems in India – framework and application

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Summary

Semi-arid regions in India are characterized by agriculture-based livelihoods and an exposure to increasing frequency of extreme weather events. To adapt to the variability in rainfall and improve access to water resources, the practice of watershed development (WSD) has been adopted across India for about four decades now. The rising frequency of extreme weather events and uncertainty around climate change projections call for assessing the resilience of WSD in India.

We develop and customize a framework for assessing the resilience of farming systems in India through a case-study. The customization includes appropriate choices of system functions, indicators and resilience attributes. Insights from literature and field-testing showed us the need to broaden the range of resilience building actions considered. This was done by explicitly focusing on the resilience capacities of transformability and anticipation, in addition to other capacities of robustness and adaptability.

Key words:

resilience; semiarid; watershed development; climate change adaptation; India

Introduction

Dryland ecosystems consisting of arid, semi-arid and sub-humid climate cover about 55% of the areal extent in India. Semi-arid regions alone account for over 1/3rd of India's areal extent and are quite dynamic, influenced by anthropogenic land-use changes as well as changes to temperature and precipitation patterns (Ramarao et al., 2019). Even small changes in the temperature and rainfall patterns can impact natural resources like – water availability, soil health, forest cover, pasture land – and in turn the agrarian livelihoods of the vulnerable communities who live in these regions (Ramarao et al., 2019).

To adapt to the variability in rainfall and improve access to water resources, the practice of watershed development (WSD) has been adopted across India for about four decades now (Gray & Srinidhi, 2013; Wani, Rockstrom, & Sahrawat, 2011). While the WSD assessments to date have focused on biophysical and socio-economic indicators, the rising frequency of extreme weather events and uncertainty around climate change projections (Eckstein, Künzel, Schäfer, & Winges, 2019) call for a longer term assessment of the resilience of WSD in India.

Several frameworks exist to assess the resilience of socio-ecological systems, and more specifically of farming systems (Quinlan, Berbés-Blázquez, Haider, & Peterson, 2016; Walker & Salt, 2012). One aspect that most frameworks agree on is the need to adapt and operationalise the steps and indicators to the local context. Given the extent of semi-arid regions in India and their vulnerability to climate change there is a clear need for a context specific, climate resilience assessment framework.

The objectives of the research work were, therefore, to:

1. Develop a framework to assess the climate resilience of semi-arid farming systems in India, with an appropriate set of indicators
2. Test and apply the framework to study the resilience of WSD in India through a case-study

Review of existing resilience assessment frameworks
Resilience assessment has been described as an important first step in holistically managing the resilience of a socio-ecological system (O'Connell, Walker, Abel, & Grigg, 2015). The system of interest in this research are rural watersheds, where agriculture based livelihoods is the primary function.

O'Connell et al. (2015) review and describe some of the weaknesses in existing frameworks for assessing resilience of socio-ecological systems such as, who is included in the process and a narrow understanding of resilience focusing on status quo. A framework by Meuwissen et al. (2019) attempts to address these issue with a more holistic understanding of resilience in the following 5 steps: 1. Resilience of what, 2. Resilience to what, 3. Resilience for what purpose, 4. What resilience capacities, and 5. What enhances resilience. As per Meuwissen et al. (2019), early application of the framework suggests that it fares well for assessing resilience capacities of robustness and adaptability, but may need further research for assessing the capacity of transformability.

The framework by Meuwissen et al. (2019) was developed for European farming systems. A socio-economically dynamic region with much greater vulnerability to climate change, such as India (Eckstein et al., 2019), needs a framework that is customised to its development context.

Another framework that builds on a similar holistic understanding of resilience, but perhaps better suited to assessing transformability is the Resilience, Adaptation Pathways and Transformation Assessment (RAPTA). Developed primarily for dynamic, development contexts in Asia and Africa, the RAPTA framework complements the conceptual strength of the Meuwissen et al. (2019) framework with its practical recommendations of iterative assessments and reflective learning.

Methods and case-study
Our new framework evolves from existing literature on resilience assessments, and in particular the two frameworks by Meuwissen et al. (2019) and the RAPTA by O'Connell et al. (2016). Developing the framework followed an iterative process. The first iteration involved broadly following the 5-step Meuwissen et al. (2019) framework, and incorporating inputs from the RAPTA framework in step-5 and in an additional step-6. At each step we considered ways in which the framework can be customised through context specific indicators and resilience attributes.

The next steps in the research involved applying the new framework to study the resilience of WSD in India through a case-study. The watershed of Kalamkarwadi, located in the Ahmednagar district of Maharashtra, was chosen as the site for the case-study based on its history of watershed development interventions, data availability, and consent from local community for the study.

A mix of focus-group discussions and stakeholder workshops were used to carry out the assessments in a participatory manner. The final step of the research involved reporting back to the community and reflection on the resilience assessment. This step helped to improve the assessment methodology and validate the results. Insights from the case-study also helped in customising the steps and indicators developed in the new framework.

Results and discussion
The key result of the research is the development of a new 6-step framework, with its customised steps and indicators, specific to semiarid areas in India. We call the new framework the Climate Resilience In Semiarid India (CRISI) framework (phonetically similar to *Krisi* or *Krishi* that translates to agriculture in Hindi). The details of each step of the framework is elaborated in Table 1.

Table 1: Steps of the Climate Resilience In Semiarid India (CRISI) framework

Step	Details
1. System Description	1.a) Describe the context and explore the stakeholders' views of the system, including what they value and why 1.b) Identify stakeholders and governance structures within the system 1.c) Discuss the scope of the resilience building interventions and the scale
2. Challenges	2.a) Explore stakeholders' views of what stresses they have faced and what they anticipate, including short-term and long-term views 2.b) Describe the environmental, economic, social and institutional issues and stresses

3. Functions	3.a) Discuss the different functions (services) provided by the system and indicators to reflect their functions 3.b) Assess the performance of these indicators in response to (specific) known stresses
4. Resilience capacities	4.a) Discuss actions taken to cope with stresses on the system, including those with short-term and/or long-term implications 4.b) Assess the contribution of the actions to the resilience capacities of the system (anticipation, robustness, adaptability, and transformability)
5. Resilience attributes	5.a) Discuss the list of resilience attributes identified for semiarid farming systems and their relevance to the local context 5.b) Assess the status of these attributes over the assessment period
6. Learning and reflection	6.a) Discuss the outcomes of the resilience assessment with the community, reflecting on its accuracy and making revisions, when required 6.b) Over the assessment period, reflect on the adequacy of the resilience building measures and need for additional adaptation or transformative changes

To arrive at a customised list of expected functions and indicators in Step 3, we relied on literature dealing with resilience of farming systems (Paas et al., 2019) and impact assessment of WSD in India (Kerr, Pangare, & Pangare, 2002). In the Indian context, we added two new functions of the watersheds – 1. Social organisation; and 2. Equity, in terms of access to employment and standard of living. Field application of the CRISI framework further showed that reduction in distress migration is a very important indicator related to Equity and standard of living function.

The new frameworks expands the possible range of resilience building interventions that can be assessed by adding the resilience capacity of anticipation (Mathijs & Wauters, 2020) to the three used by Meuwissen et al. (2019). Given their experiences of frequent droughts and the recent COVID-19 pandemic, this was a capacity farmers were quickly able to relate to.

The new framework addresses some of the bias in earlier frameworks towards status-quo oriented resilience and adaptability with its focus on transformability. This is achieved through the introduction of step-6 on Learning and reflection as well as including a specific resilience attribute on governance arrangement that support transformation.

The list of resilience attributes in Step 5 were initially derived from literature (Cabell & Oelofse, 2012; Paas et al., 2019). Field application of the CRISI framework helped in removing redundant attributes and those not relevant to the local context.

Conclusions

The CRISI framework evolves from existing literature on resilience assessments and makes improvements through three key aspects:

- The indicators and resilience attributes are customised for semiarid areas and developing contexts
- Through its focus on transformability, it addresses some of the bias in earlier frameworks towards status-quo oriented resilience and adaptability
- It includes anticipation as a resilience capacity that broadens the possible range of resilience building interventions that can be assessed

The framework has direct applications in resilience assessments to generate evidence-based insights that can guide government programmes effecting the livelihoods of vulnerable communities. It can also be used in project planning and mid-course corrections. While it has been developed for semiarid farming systems in India, it also has the potential to be applied in other developing countries.

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A. Designing resilient systems
A.s4. Designing resilient and sustainable EU-farming systems; which innovations are needed?

Application of resilience in nature policy: assessing alternative futures to 2050

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Summary
Building resilience to climate changes and environmental risks is acknowledged explicitly in the new EU biodiversity strategy, in line with the new Green Deal and other related policies. As an EU Member State, Dutch nature policy also takes this up, seeking to build a 'strong and resilient nature'. We evaluate different Dutch Nature Futures to 2050 using principles for enhancing the capacity of social-ecological systems to sustain desirable nature futures. Assessing based on resilience principles, helped to identify undesirable pathway dependencies (lock-ins) in the Dutch Nature Futures 2050, where undesirable resilience needs to be reduced to make way for more transformative development pathways. It also shows entry points to improve the resilience of socio-economic systems where nature and biodiversity play a more prominent role. The possibilities to adapt are much greater when the evaluation score on the principles is relatively high. In such a way, the possibilities to improve the resilience of desirable trajectories and reduce undesirable ones can be investigated in a structured way by applying resilience principles. The principles offer a recognizable structure for comparing different future scenarios.

Keywords
Dutch nature futures; resilience principles; transformative development pathways; evaluation scores

Introduction
The Netherlands have embarked on a national 'Nature Exploration 2050', which provides scenarios of how Dutch nature could develop until 2050, given established policies, actions and expected developments. The aim of this paper is to explore how resilience can be used to assess and contribute to these Dutch nature scenarios, with a view to providing practical application on the use of resilience to achieve the 2050 biodiversity outcomes. We start with clarifying the main interpretations of resilience as it has evolved over time and reflect on whether existing application in nature policy has kept pace with this evolving concept. Using this information, we develop an assessment framework for systematically evaluating resilience of alternative nature futures. We apply this to two of the Dutch nature scenarios. We compare our findings across each scenario and draw recommendations for how to best operationalize resilience concepts in envisioning nature futures.

Conceptual outline of resilience
There are many different ways that resilience is used in practice (Walker 2020; Meerow et al. 2016; Elmqvist et al. 2019). A too narrow in application of resilience can be highly problematic as it ignores the inevitable feedbacks, unintended consequences and inequities among other interacting dimensions. To address these concerns, ecological resilience was broadened to explore resilience of social-ecological systems (Fischer et al., 2015). This systemic perspective assumes that social systems (including (agricultural) economic systems) and ecosystems are inextricably linked, and feedbacks between them produce emergent, system-level outcomes and properties that are different from those of the individual parts (Folke et al. 2002). These feedbacks can be positively or negatively reinforcing and understanding this provides an entry point for identifying lock-ins that drive desirable or undesirable outcomes (Blythe et al., 2017). In this view, resilience is a system property and is applicable to different subsystems. It can be good or bad, depending on whether this resilience reinforces desirable or undesirable outcomes (Walker, 2020). Resilience is framed around the ability to live with change and continue to develop and is defined as a "system's capacity to cope with shocks and undergo change while retaining essentially the same structure and function" (Walker et al. 2009). This capacity stems from interacting properties and government of the systems and sub-systems, and numerous frameworks have been developed for measuring this capacity (Wardekker et al., 2020, Biggs, 2012, etc.). Biggs et al. (2012) distill seven generic principles for enhancing the capacity of social-ecological systems to sustain delivering desirable sets of ecosystem services in the face of ongoing change.

Methods and case studies

The work of Biggs et al. (2012) formed the basis for developing our resilience evaluation framework, which is applied to the case of two recent Nature Outlooks for the Netherlands. By applying the resilience principles as developed by Biggs et al. (2012), our work includes a number of main building blocks for evaluating resilience of Nature Outlooks grounded in a conceptual and methodological framework. Experts with backgrounds in ecology, economics, planning and governance have been engaged in judging the resilience of the Nature Outlooks, through an expert workshop. Our approach is similar to Lindow et al. (2020) who interpreted principles as "important features of complex systems that may contribute to the emergence of resilience". Different principles, factors or indicators have been developed to describe how to enhance (or undermine) resilience (e.g. Biggs et al, 2012; Cinner and Barnes, 2019; Ungar, 2018; Wardekker et al., 2018; Cabell and Oelofse, 2012, and Wardekker et al., 2020). We examined this literature as a basis for developing working principles for evaluating nature futures and concluded that Biggs et al. (2012) provided an adequate and relevant starting point. We therefore adopted the Biggs et al. (2012) principles and used these as a tool to assess and reflect on the resilience of the Dutch nature futures. The first three principles of Biggs et al. (2012) evaluate the key social-ecological system properties that need to be managed, and we evaluated these across biophysical (including ecological and climate dimensions), socio-economic (including technological, social and economic dimensions) and governance dimensions.

The Netherlands regularly develops and evaluates different scenarios of nature futures as part of its nature policy since 1997. These are intended to guide policies, strategies and social discussion about the future of nature in the Netherlands. The Nature Exploration 2050 forms part of this legal obligation. We assessed the relative resilience of the two most opposite scenarios of the Nature Exploration 2050: the 'Business- as- Usual' scenario (BAU) and 'Sharing the planet' scenario (BDB). The 'Business- as- Usual' scenario (BAU) is based on extrapolating past trends in driving forces into the future. It serves as a reference scenario against which alternatives can be compared. The BAU presents a future 2050 focused mainly on the ambitions of existing nature policy and development trends in other sectors (agriculture, urban, water and energy). The BDB is a highly exploratory policy scenario (Kok and Immovilli, 2020), which extends nature policy objectives into new directions, mainly by exploring synergies with adjacent policies such as climate, agriculture, water and cities. The BDB acknowledges the inextricable linkages between nature and society and seeks to accomplish joint outcomes with a much broader set of agendas. It is in line with international developments currently taking place in five domains: agriculture, sustainable cities, green public spaces, climate adaptation and water management.

Results

The BAU performed poorly compared to the BDB in terms of Principle 1: Maintain diversity and redundancy; Principle 2: Manage connectivity; and Principle 3: Manage slow variables and feedbacks. Almost all the dimensions for these principles scored below average relative to the BDB. The BAU performed particularly poorly for the governance of slow variables and feedbacks and maintaining diversity and redundancy of the biophysical environment: the low score of the former reflects the tension of balancing short-terms gains with long-term objectives, particularly in the shorter political cycles. The low score for maintaining diversity and redundancy of the biophysical environment reflects the very narrow scope of current nature policies, which focus on 'locking away' a limited subset of species and habitats in protected areas, without explicit consideration of the full set of biodiversity and the benefits that ecosystem services can provide society. The BDB performed better than the BAU, although none of its principles were regarded as fully achieved. The strongest gains made by the BDB relative to the BAU were around expanding the scope of nature policy to seek synergy with other policy goals, which helped to include a much broader suite of species, habitats and ecosystem services. Strong gains were also made in the governance of slow variables and feedbacks, mainly as a result of improved adaptive governance processes, which catalyze feedbacks between what is monitored and interventions that are put in place as a result. Despite the strong gains, the BDB scored below average for the socio-economic dimension of Principle 3 (Manage slow variables and feedbacks), reflecting severe lock-ins resulting from dependency on market regulation, which does not adequately account for longer-term social and environmental costs.

The BDB certainly incorporates more systemic resilience than the BAU, but never scores full points. The most limiting factor in the BDB is Principle 3 (due to strong lock-ins and required regime changes), while the governance-related principles score much better (as a reflection of broader participation).

Discussion and conclusions

We distinguished different dimensions of the SES (biophysical, socio-economic, and governance) in analyzing resilience through the principles enhancing resilience as distinguished by Biggs et al., 2012. This is in line with a recent plea of Walker where he argues that considering both resilience of parts of the system to specific threats and the whole system covering all parts is necessary (Walker, 2020). In addition, all the properties/parts of the system are influenced through the way the system is governed. This is in line with the findings of McKay et al. (2020) on the relation between increases in the perceptions of improved governance quality and resilient SES outcomes. We were able to use the principles to systematically compare the resilience of alternative nature futures. Some of these resilience dimensions were already at a relatively high level and for these it is likely that adaptation pathways to facilitate ongoing learning, experimentation will be required. There are other resilience dimensions that perform poorly in both the BAU and BDB – these point towards path dependencies and lock-ins, which will require transformative where undesirable system resilience may need to be reduced to make way for alternative new development trajectories. By evaluating each of these principles we were able to identify where transformation of the current trajectory is required. This is particularly the case where the BDB also scored low, as these indicate lock-ins. We expect that there is major lock-in in the socio-economic system that prevents management of slow variables and feedbacks, as reflected by the lowest score in the BDB. The impact on connectivity, diversity and redundancy was less important compared to managing slow variables and feedbacks. The SES governance properties in BDB could be improved further by focusing on the governance of diversity/redundancy and management of connectivity.

We found that the resilience principles help to think systematically through how to develop nature futures that foster resilience. The comparative analysis of alternative futures relative to a BAU indicates how to improve resilience. It is also possible to assess resilience along the pathway towards this future. Resilience capacity will be much higher when the scores on the principles are high. Creating conditions for resilience of ecosystem services production in nature outlooks can be improved in a structured way by applying resilience principles as they offer a structure to compare different scenarios.

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MODELLING COMPLEX AND INTER-DEPENDENT STE SYSTEMS

TRACK B

Effects of multi-level governance characteristics on resilient flood risk management: Case study of Kerala

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Summary

Recent floods in Kerala, India have led to the loss of many lives and extensive property damage. Regardless the socio-economic impact of the floods, there is lack of understanding of their underlying factors. Apart from the climate change, it is the poor urban governance that undermines flood resilience of Kerala. Among the most challenging governance issues are corruption leading to illegal mining and environmental degradation, and response-centric disaster management. This research aims to explore the ways in which the current governance arrangements can be improved. In order to achieve that, we use agent-based modelling to simulate behavior of governance arrangements in four the phases of resilient flood risk management (resist, response, recover and reflect). In the simulations, we investigate how multi-level governance characteristics (such as self-organization and power distribution) contribute to resilience. We conclude our preliminary results with recommendations for resilient flood risk management.

Keywords
resilient flood risk management; multi-level governance; MAIA; agent-based modelling

1. Introduction

Kerala is the south-western state on the Malabar coast of India. It is well-known for its abundant water and mineral resources (Tharoor, 2019). The Kerala flood in 2018 is described as the most catastrophic flood in history since the 1924 flood and this elevated the concerns of the public with respect to disaster management (Nowfal & Sarath, 2018). From 1 June to 20 August 2018, the quantity of rainfall in Kerala increased by 140 percent in comparison to the normal level and resulted in floods, causing damage to both life and property (Oommen et al., 2018). The media reported the loss of 500 lives and evacuation of over a million people (Chandran, 2019).

In general, Indian coastal regions are vulnerable due to – climate change and opulent monsoons, high population in the coastal area, growth in population, rapid and uneven development (Mathew, Trück, & Henderson-Sellers, 2012). With respect to Kerala, in addition to that, the state is facing consequences of institutional incapacity that resulted in outdated dam management, increase in mining, development in Western Ghats mountain range and lack of prediction systems (Padma, 2018). The disaster management system in Kerala is response centric (Shaharban & Rathnakaran) that misses anticipatory and participatory approach. The floods emphasize structural constraints in relation to institutional capacity, policy and planning, financing, standards, access to data and public services which resulted in Kerala being unprepared for severe natural calamities or climate change (Chandran & Paul, 2019). The 2018 floods were also the consequence of ineffective communication, lack of structure in capturing local knowledge, lack of support offered to non-government organizations and voluntary social welfare institutions, privatization of nature and fragile zones and failure to involve the local-self-governments in the decision-making process (Singh et al.,2018).

The 2018 flood indicated many flaws of the current governance system, and the need to determine measures for building flood resilience. In response to this, we aim to explore the ways in which the current governance arrangements can be improved. In this light, our research develops an agent-based model to better understand interactions involved in flood risk management. To pave a preliminary path to building flood resilience, our model focuses on the phases of resilient flood risk management and characteristics of effective multilevel governance arrangements.

2. Theoretical background

2.1. Resilient flood risk management

In the context of disaster risk, resilience of a system exposed to hazards is the ability to resist, absorb, accommodate, adapt to, transform and recover from the impacts of the hazard efficiently ensuring the preservation and restoration of its essential basic performance through risk management (UNISDR, 2009). According to Batica et al. (2013) adding resilience to flood risk management is about incorporating the characteristics of resilience into the traditional flood risk management cycle which includes, mitigation, preparedness, response and recovery. In this research, we adapt the work of Batica et al. (2013), and use the resilient flood risk management cycle that comprises four phases: resist, response, recovery and reflect (fig. 1).

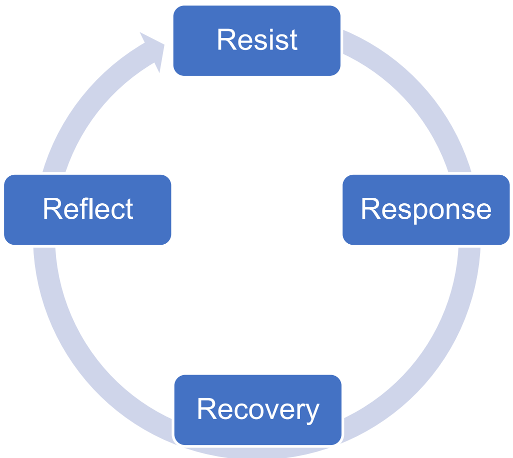

Figure 1. Phases of resilient flood risk management.

Table 1. Definition of the resilient flood risk management phases. Adapted from Batica et al. (2013)

Phase	*Implementation phase*	*Function*
Resist	Before the flood	Mitigate flood risk and enhance threshold capacity by adaptation measures to limit flood damage and ensure ease of response and recovery
Response	During the flood	Implement crisis management measures
Recovery	After the flood	Restore damaged infrastructures and livelihoods, and support communities
Reflect	After/Before the flood	Increase awareness, engagement and adaptive capacity by learning and transforming. Management at all levels – policy level, professional and public participation

According to Batica et al. (2013) incorporating resilience into the flood risk management calls for evaluating resilience through five dimensions – natural, physical, economic, social and institutional. The main goal behind these dimensions is to evaluate the ability of an urban system to prepare for, respond to and recover from a disturbance.

2.2. Multi-level governance

Flood risk management is a complex process which requires engagement of many stakeholders located at multiple levels. According to Parsons & Skinner (2018), Kerala flood showed that there must be cooperation among governments, both regional and national, along with agencies and first responders. Furthermore, the experience indicated the requirement for a more effective communication and public engagement to develop flood risk literacy and the need to understand the dynamic nature of the system as the flood risk assessments previously considered was a static, steady-state system which did not prove to be representative of the real-life case (Parsons & Skinner, 2018). Flood risk management is a public good/service (Geaves & Penning-Rowsell, 2016), which requires multi-level governance for its resilient provision (Djalante, Holley, & Thomalla, 2011).

Multi-level governance (MLG) helps in establishing a balance between 'bottom-up' and 'top-down' approaches and offers a way to address complex issues that cannot be solved at a single level. MLG offers flexibility by accommodating the changes in citizen preferences, enhances problem solving capacities and prevents cross-jurisdictional spillover by clustering competencies that are spread across jurisdictions (Hooghe & Marks, 2010). In addition to capturing the formal institutions, it enables to study the informal institutions governing interactions (Hooghe & Marks, 2010). The MLG has a significant impact on the capacity to manage resilience as it promotes self-organization and formation of networks (Djalante, Holley, & Thomalla, 2011). Considering the above, implementing MLG approach would contribute to addressing majority of the technical and institutional issues related to flood risk management.

3. Research scope

In order to study the effects of MLG characteristics on resilient flood risk management, this research considers the MLG structure of the port city of Kochi, the largest urban agglomeration in Kerala, which constitutes stakeholders from different levels – National authorities, State authorities, District authorities, the local self-government (Kochi Corporation), NGOs and community initiatives.

Several governance issues have been highlighted by researchers (Singh et al., 2018). This research will focus on the following MLG characteristics that revolve around governance issues:

1) overlapping jurisdictions—incapability of government authorities to give precise answers on their roles and responsibilities;

2) power distribution and decentralization—low involvement and empowerment of local-government in the decision-making pertaining to flood risk management;

3) horizontal and vertical collaborations—weak involvement of NGOs and social welfare institutions.

In addition the research investigates the transaction costs involved in the activities that are carried out.

4. Agent-based model

Agent-Based Modelling (ABM) follows the agent paradigm according to which a system consists of several interacting social entities and technical subsystems (van Dam et al., 2012). ABM models socio-technical systems and throws light into the dynamics and structural change arising from the interactions in the system (van Dam et al., 2012). In this research, we use ABM to study the interactions between the stakeholders involved in the flood risk governance arrangement of Kerala and study the effects of multi-level governance characteristics on enhancing flood resilience.

Our conceptual model is developed using meta-model MAIA (Modelling Agent systems based on Institutional Analysis) (Ghorbani, Bots, Dignum, & Dijkema, 2013). MAIA is representative of Ostrom's Institutional Analysis and Development framework and it works on the principle that social interactions are influenced by institutional arrangements. The objective of using MAIA is to prepare a layout of the complex system by identifying crucial aspects of the system that has be modelled to capture the essence of governance dynamics.

In addition, we model governance interactions in four phases of resilient flood risk management (resist, response, recover and reflect). We evaluate the flood risk management cycle by taking into account through five dimensions – natural, physical, economic, social and institutional. In the phases of resilient flood risk management, certain activities or interactions contribute to each of the dimensions resulting in the evaluation of the performance of the existing resilient flood risk management setting of the urban system (Fig. 2).

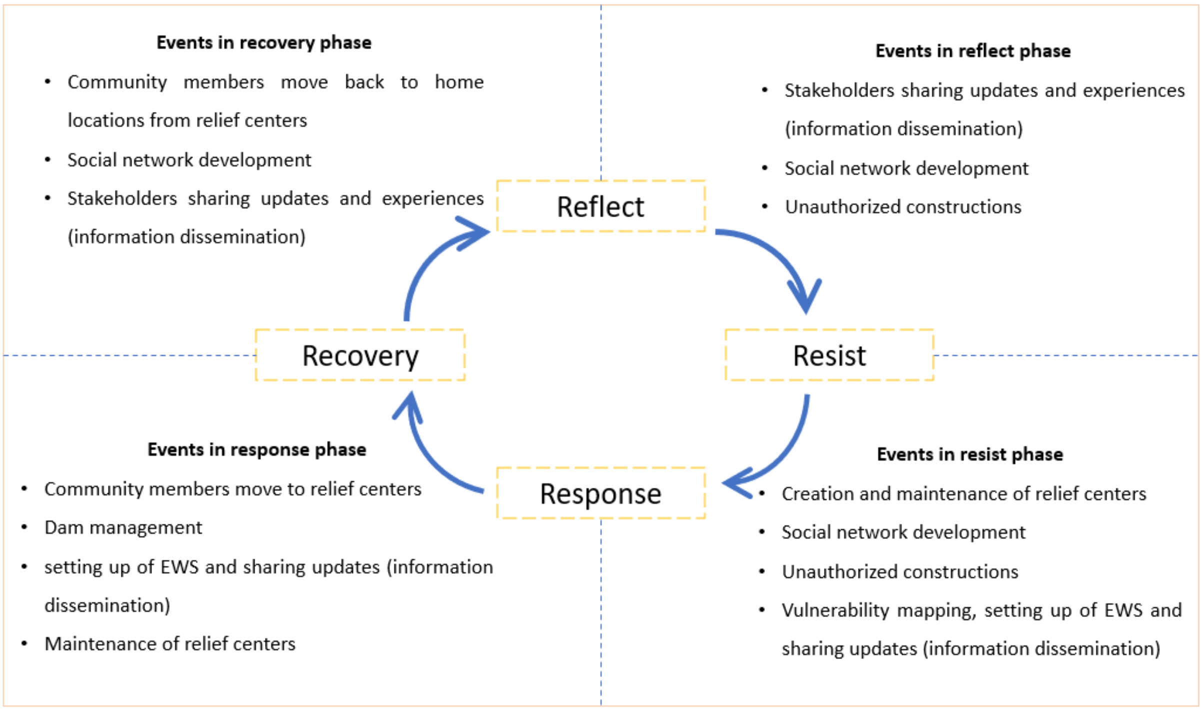

Figure 2. Events and interactions captured in the model.

5. Conclusion

This study explored the effects of multi-level governance characteristics on resilient flood risk management in Kochi agglomeration. The results of literature review and interview showcased significant differences between the existing formal rules and their implementation in practice. In particular, our analysis highlighted that the current overlap in jurisdictions affects the clarity of responsibilities. This finding was used as an important input to develop the ABM model, and contributed to studying power distribution within the existing multi-level governance structure. Overall, the ABM results revealed that the District and Local authorities should be more involved in the decision-making pertaining to flood risk management, and the collaboration network among community members, NGOs and government authorities should be strengthened. Finally, our research highlights the importance of "policy switching" along resilient flood risk management cycle, which assumes combining different power distributions in line with the needs of flood risk management phases.

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An Agent-based Model for Considering Human-infrastructure Interactions in the Resilience Assessment of Power Networks

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Summary
The inequities exist in the impacts of natural hazards on the affected communities calls for approaches which consider the social aspects in the resilience assessment. In this study, we developed an agent-based model which will not only consider the physical impacts on the infrastructure systems but also includes the households' tolerance and protective actions for mitigating the risks. The model consists of 1) the hazard component which exposes the community to a hurricane with varying intensity levels, 2) physical infrastructure modelled as power networks which provide electricity to the residents, and 3) affected households who prepare for the upcoming hazard and experience the power outages caused by the hurricane. The model assesses the extent of hardship that the community experiences from the power outages. This model provides a tool for experimenting scenarios which would lead to varying hardship levels to the residents of an affected community. The results of the model help disaster managers and utility companies in making informed decisions which consider the specific needs and expectations of the communities.

Keywords
Agent-based modelling; infrastructure systems; equitable resilience; societal expectation

Introduction
The assessment of the impacts that natural hazards pose on the affected communities has been mainly focused on either physical or social systems of a community separately. Individual assessment of the risks of natural hazards fails to consider the unequal capabilities of the households tolerating the negative impacts. Households are heterogeneous in the resources they hold and their capacity of withstanding the impacts of natural hazards. Therefore, there is a need for integration of the physical and societal impacts of natural hazards in the resilience assessment of the communities.

Infrastructure services play a critical role in providing essential services to the communities. The extensive exposure of these services to the hazards and the interdependencies among these systems, however, makes them highly vulnerable to the failures due to natural hazards (Applied Technology Council 2016). Recent research has shown that the impacts of such system failures are not equal in the communities and socially vulnerable population are disproportionately affected by such service disruptions (Coleman et al. 2019; Dargin, J., Mostafavi 2020). The disparities in the impacts of such service disruptions are due to both their higher exposure to the service disruptions and their lower tolerance for such disruptions (Esmalian et al. 2019). Therefore, it is essential to consider the unequal tolerance of the households when assessing the impacts of service disruptions on the communities.

Agent-based modelling (ABM) has the advantage of enabling the consideration of the heterogeneous agents in a system. Therefore, this ability makes it a proper fit for considering the unequal tolerance of the households and examining the disparities in the societal impacts of such service disruption in the communities. In addition, ABM enables the consideration of the interactions among the households. Households in the community interact with each other and decide to take protective actions depending on their own perception of the risks and their immediate social network's actions. Thus, the protective action mechanisms of the households in preparation for a natural hazard could be properly modelled in

ABM. Therefore, we implemented an ABM to examine the impacts of the hazard on a community based on the individual household's behaviour in tolerating the service disruptions.

Model Description

In this study, we developed an ABM to examine the impacts of power outages on the affected communities. The hurricane model would pose different levels of the power outages on the community depending on the physical characteristics of the power network. Households will take protective actions based on the information they receive, their perception of the risks, and their social network's actions. Then, their tolerance will be determined and compared to the level of disruptions, which has been occurred in their power zone, to assess their experienced hardship. The model results highlight the hardship profile of the communities and enable examining the impacts of varying hurricane intensities based on the physical condition of the power network and household's protective actions for tolerating the disruptions.

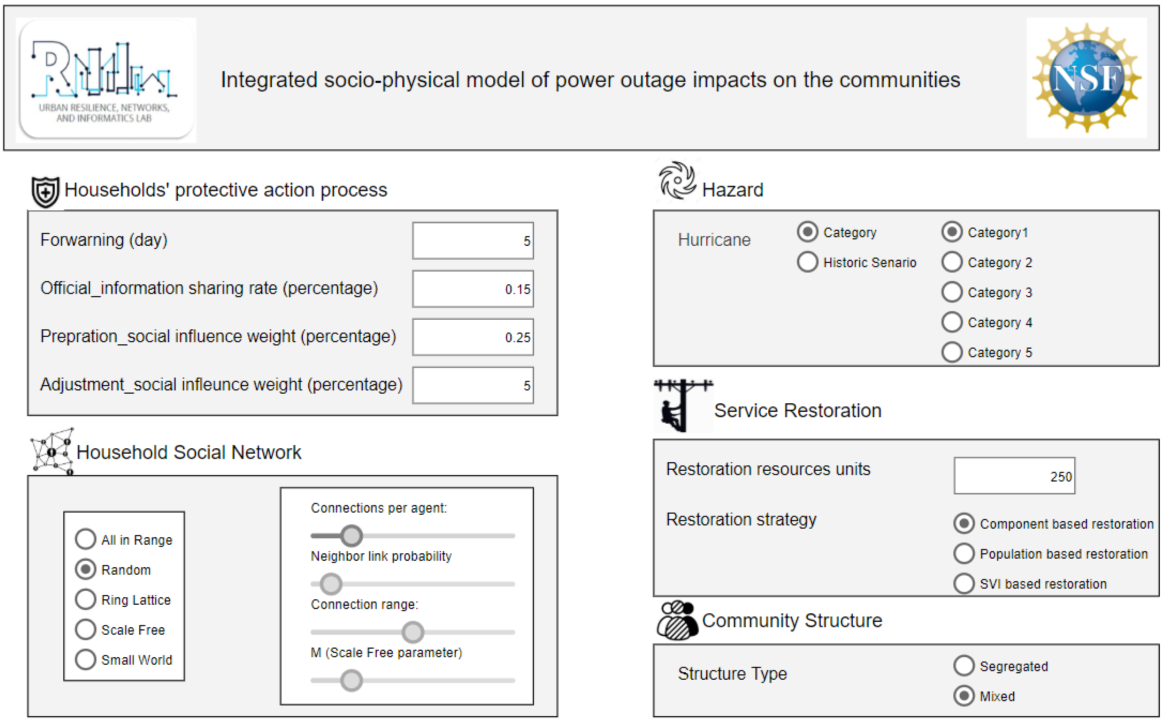

Figure 1- Input dashboard of the agent-based model

The ABM consists of the hurricane model, household characteristics and the power network characteristics, as shown in Figure 1. The hurricane model includes different hurricane categories and also the historical wind speed of Hurricane Ike and Hurricane Harvey. The wind speed values are integrated using HAZUS-MH wind model (Vickery et al. 2006). Here. The wind model generates the wind speed values for each census tract in Harris County and poses threats to the power network. The power network in this study is developed using a synthesized power network developed by Birchfield et al. (2017) and Gegner et al. (2016). The synthesized power network represents a near-real representation of the power network in Harris County. Fragility curves are then used to model the failure in the different component of the power network. The model also considers the cascading failures due to the interdependencies among the components of the power network.

After the failure in the power network, the utility provider sends the repair units to restore the damaged components of the power network. Each component requires a certain number of units for the restoration, and the power company restore the service depending on its available units and the restoration strategy. Then, households depending on the power zone in which they live would experience different levels of the power outages.

Households' protective actions are influenced by the social influence of their network, as well as their information-search behaviour. Protective actions affect the household's tolerance for the disruptions. In this study, empirical data from household surveys from three hurricanes (Harvey, Florence, and

Michael) are used in conjunction with theoretical decision-making models to simulate the underlying mechanisms affecting the protective actions of households. Households first receive information about the upcoming hurricane and form a perception of the potential duration of service losses. Then, they decide if they would take protective actions based on their own characteristics and the influence of their social network. The protective action of the household and their inherent needs and expectations from the services would determine their tolerance level for the power outages. Empirical models based on the survey data were used to develop the model for determining household tolerance. Finally, the household's hardship status would be determined based on their tolerance and the duration of the outages they experience.

The simulation model outputs the results for both the physical and social aspects of the impacts (Figure 2). The extent of damage to each component of the power network and the profile of service restoration assist in the assessment of the physical impacts on the system. The percentage of the households experiencing hardship from the power outages is reported as the indicator of the societal impacts on the community. The results of the model provide a tool for testing different scenarios of impacts. Specifically, the impacts under different durations of forewarning, various level of social network connectivity, and service restoration strategies could be tested to develop plans aiming at mitigating the societal risks of service disruptions.

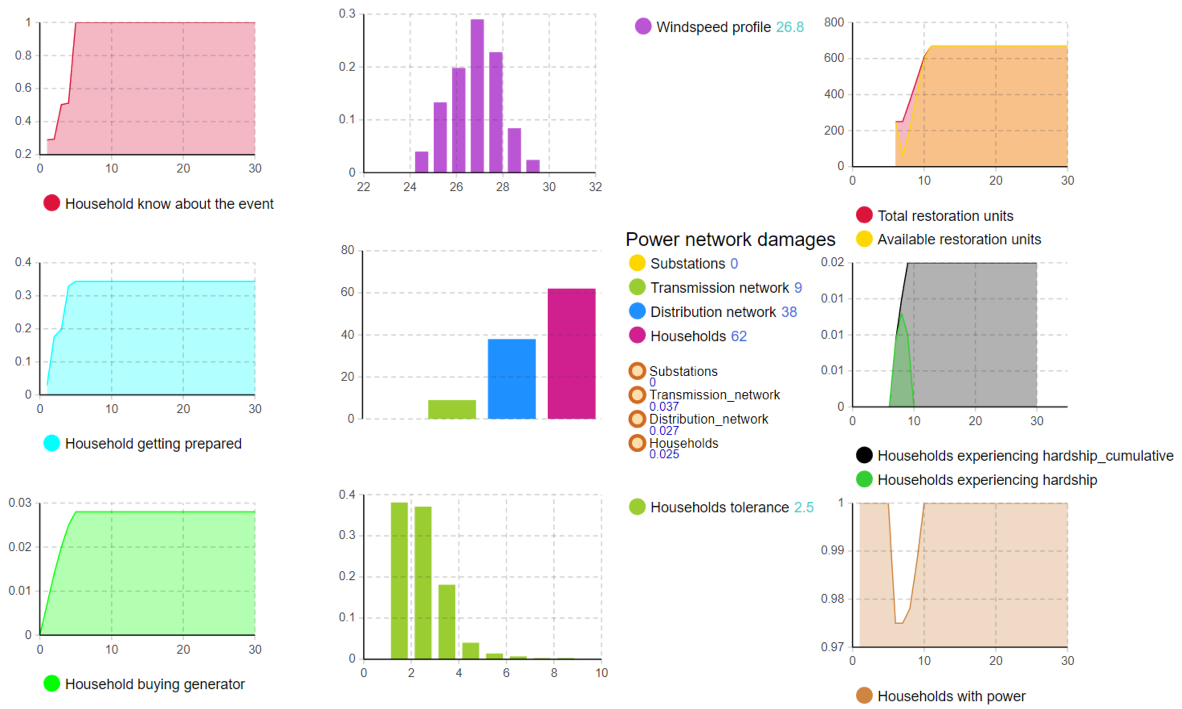

Figure 2- Output of the agent-based model

Conclusion

This study presents an integrated socio-physical agent-based model to comprehensively assess the impacts of the natural hazards on the affected communities. The agent-based simulation model could be used to examine the effects of different public warnings, information treatment, and restoration resource allocation strategies to reduce the societal risks of service disruptions. The results of ABM show the capability of the proposed model for integrating the household's protective action behaviour in societal risks to prolonged power outages. Hence, the model enables integrating human-centric aspects in resilience planning and assessment of infrastructure systems in disasters.

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Modelling complex and interdependent STE systems
Agent-based modelling and simulation for the assessment and design of STE systems

Nested multi-input-output model of interdependent infrastructure and socioeconomic systems in urban areas

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Summary
Urban areas are constantly expanding as people gravitate towards cities. As a result, cities become more complex, interconnected, and dependent on essential infrastructure systems. These systems are stressed and suffer more disruptions. In turn, these disruptions have larger impacts due to higher urban density and increasing number of interdependencies present. Consequently, it is vital to ensure that the infrastructure systems are resilient. We present a framework for modeling impacts of disruptions on infrastructure systems, businesses, and households in urban areas. Our novel model addresses the gap of adequately modeling non-homogenous urban areas. These areas might benefit from more detailed representations in regions of particular interest. We outline the approach and key issues in this space, such as mapping of resources between models of different granularity and defining the most adequate granularity levels. Finally, we describe the main challenges and possible further studies focused around the application of this model in practice.

Keywords
Infrastructure modeling; system-of-systems; agent-based modeling; infrastructure resilience; model granularity

Introduction

Over the past years people gravitated towards cities as a result of technological advancements and the concentration of employment, housing as well as most socioeconomic institutions in urban areas. This trend is expected to continue in the near future: the UN predicts that over 60% of people globally will live in urban areas by 2030 [1]. Consequently, trends accompanying this rapid urbanization are immensely important. These include development of large amounts of dense infrastructure systems. These systems enable societies to operate by providing them with the essential functions such as transportation, water supply, energy supply, communications. These services are vital to modern societies, which cannot operate without them, especially so in urban areas. As a result, the efficient operations of these services and provision of resources that these systems are producing and delivering are crucial. It is important that governments and decision makers develop, plan, manage, and maintain these infrastructures in a way that ensure their smooth running.

The development of infrastructures, as well as the abovementioned rapid urbanization, however, stress infrastructure system and lead to increasing numbers of disruptions in such systems, along with increased impacts of these disruptions. This is due to several factors. First, the density of urban areas and infrastructures increases, which leads to more events happening in the same area, and similarly to growing impact of events that affect the same area. Second, modern infrastructures become extremely interdependent forming a complex mesh of networks and systems that depend on each other. Third, these systems undergo rapid transformation and form a cybernetic organism that results in cascading and emergent impacts of seemingly separate events[2].

This poses a question as to how to design, manage and plan these, thus continuously developing, more interdependent and complex infrastructures in a way that ensures their resilience and ability to survive any disruptive events. To achieve this, we need a modeling approach that adequately represents interdependencies between infrastructure systems and socioeconomic agents of the society, which can be used to evaluate the resilience of these complex urban systems with accounting for the interdependencies between constituent systems. Hence, the aim of our work is to present a novel contribution to modeling interdependencies between infrastructure systems and socioeconomic agents, such as households or businesses, as well as the impact of disruptions, which would enable to better represent impacts of disruptions in diverse, spatially non-homogenous urban areas.

The challenge of modeling infrastructure systems and the impacts of disruptions has been attempted by several authors [3][4][5][6][7]. An interesting approach was proposed by Dubaniowski and Heinimann[8][9], who developed a multi-input-output framework for modeling impacts of disruptions on infrastructure systems, households, and businesses. Their approach combined Leontief's input-output model [10] with complex network analysis [11]. However, this approach was limited in its coverage of spatially non-homogenous areas, such that more and less densely populated areas had the same granularity of the model. Hence, our aim is to extend this model by allowing combination of several nested models of varying granularities. This would allow for varying levels of granularity to be included in one model comprising of various models with different granularities within it. The issue is also evident in other fields such as food production [12]. In this abstract, we present the preliminary study of this novel approach.

Model specification

The modeling framework utilized in this study consists of a system-of-systems model of several infrastructure systems, businesses, and households. This is an agent-based model, based on multi-layer complex network approach, where each node corresponds to a business, household, or an infrastructure system provider, and each link corresponds to an infrastructure link between these agents. Under this model, infrastructures are presented in two ways: (1) through infrastructure links between agents, or (2) through agents providing the infrastructure. Each node is formed primarily of an input-output model production process, which represents production process as a transfer of a given set of goods and services into another set of goods and services that could be produced at that agent. Transportation of goods and services happens over links, and is coordinated with a price mechanism, which ensured that cheapest resources are always utilized at each agent in a production process. The price mechanism ensures that system responds to any disruptions by rearranging the supply chains of resources in line with the disruption. The high-level view of the model is shown on Figure 1.

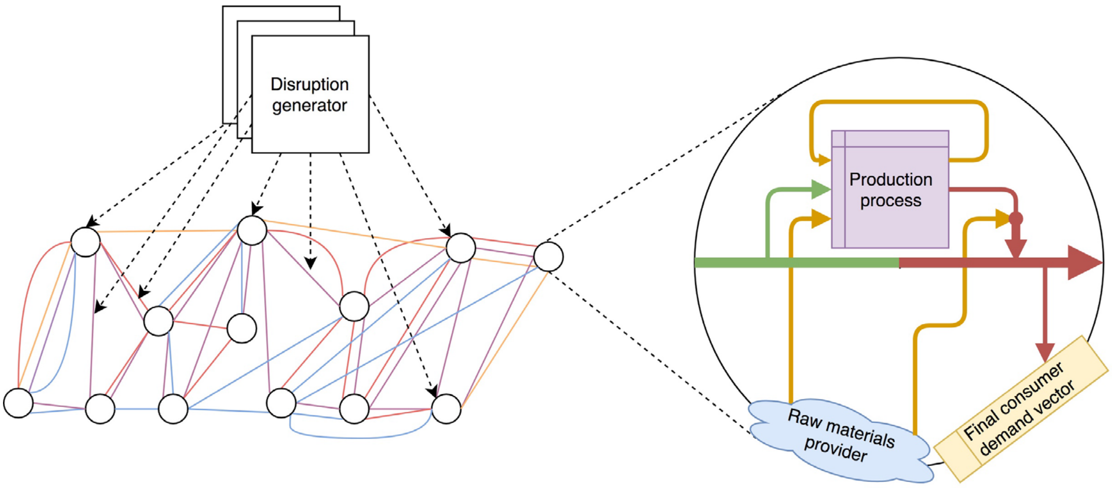

Figure 1: Multi-input output model for modeling disruptions between households, businesses, and infrastructure systems. Each node represents an agent, corresponding to a business or a household, these agents are connected with infrastructure system links.

The model described above could be used to represent urban areas in terms of infrastructure systems, businesses, and households. This is achieved by mapping a certain area to the model by assigning cells of the geographical region to individual nodes of the network. The urban area is divided in the grid, where each cell is represented by an agent-node. However, this approach makes it difficult to represent non-homogenous urban areas. For example, an industrial region consisting of a large amount of closely located factories has very different characteristic compared to a green region with sparse houses. To tackle this challenge, we propose combination of sub-models of varying granularities within one overarching model. In this approach, we represent one or more cells of a coarser granularity model with a much finer granularity model of the same type rather than with an agent-node. The finer granularity model would, for example, include more resources thus providing a better representation of the area. The coarser granularity, overarching model is still used to represent the overall urban area. This approach is presented on Figure 2. As we can see from this figure, an urban area is divided into a grid of cells. Each cell corresponds to a node of the network under the modeling framework. However, certain cells are modeled as an individual instance of the model themselves, rather than as an agent. This results in a better duality with the real-world, where more significant parts of the urban area can be presented as individual sub-models, and hence in more detail. This benefits the overall accuracy of the simulation, which is a desired outcome.

The implementation of the above simulation is achieved using the High Level Architecture (HLA) framework by combining several sub-models into one overarching model. The main challenges that need to be addressed are focused around the interfaces between different granularity models, and their levels. In particular, this includes issues such as mapping finer granularity resources to coarser granularity model's resources, and vice versa in a simulation. Similarly, it is important to formulate the adequate thresholds of granularity that should be devised in order to create an optimal simulation.

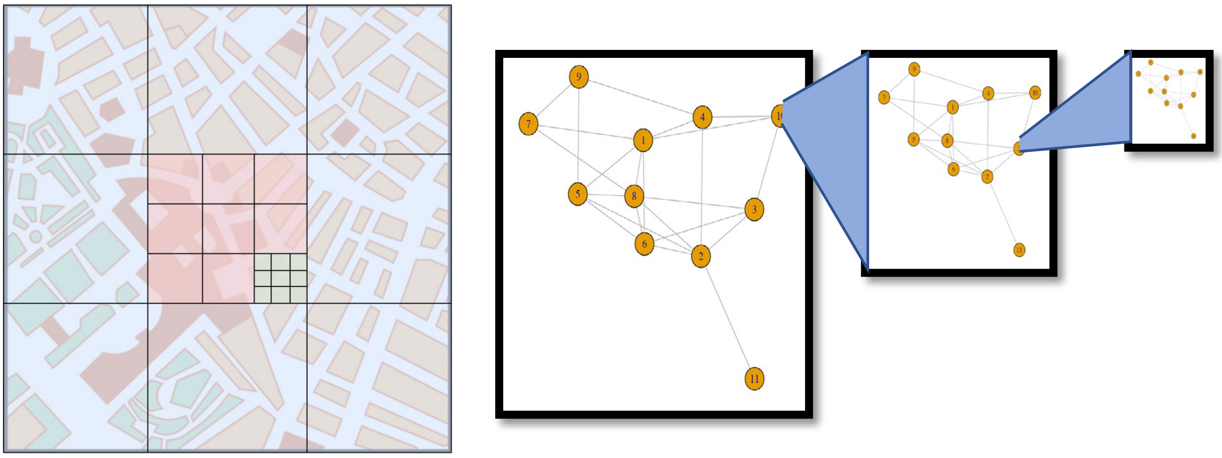

Figure 2: Nested models could be used for more complex regions. An individual agent can be represented by a separate instance of the modeling framework.

Conclusion

The aim of our study is to extend the model of interdependencies between infrastructure systems, businesses, and households by developing an approach to more adequately represent spatially non-uniform areas. This is achieved by outlining the approach of combining models of differing granularities together, thus enabling it to represent non-homogenous areas more accurately.

The major limitation and challenge of our study, is addressing the issue of mapping resources between different levels of granularity in a way that preserves their unique characteristics adequately. Furthermore, optimal levels of granularity need to be established. Finally, a universal approach for selecting the above could be formulated, so that an accurate representation of an urban area can be easily achieved. Then, presentation of the computational framework, and application of the model to a real-world scenario could be attempted.

To address these challenges, we attempt to perform analyses of different mapping functions and approaches to find an optimal solution for the considered systems. Similarly, we focus on devising an adequate depth of this nested approach. Finally, application of the nested approach to a real-world urban area is planned to evaluate the accuracy of the model and its duality with the real-world. Findings of our study could also be applied to other fields where spatial granularity modeling is of significant importance such as to food production supply chain systems modeling [12].

Acknowledgements

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An agent-based model to study resilience in a stylized social system

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Summary
For societies to adapt to climate change, it is desirable to know which conditions and responsibility arrangements in climate adaptation policy may lead to resilient and socially just outcomes. Here we present early-stage results of an attempt to operationalize resilience in a stylized social system agent-based model with unequal resource and risk distribution. In it, individuals each have an amount of resources using which they aim to reach a region of safety. Some altruistic individuals also inform their neighbours of the need to move to the safe region. As resources are distributed unequally in the system, we introduce 'resource banks' as institutions that intend to facilitate a fairer end outcome by allowing resource transfer from the well-off to those in need. Preliminary results suggest that under some conditions such institutions may be ineffective in helping more individuals reach safety. We end with a discussion of the next steps for the research.

Keywords
Agent-based modelling, climate change adaptation, resilience modelling, social justice modelling

Introduction
In order to adequately deal with climate change, we see a role for modelling to discover responsibility arrangements in climate adaptation policy that promote resilience and are ethically justified, and identifying the conditions needed for them to be effective.

Resilience is often understood as an emergent property of systems whereby they are able to adapt, recover, and maintain functions in the aftermath of shocks and perturbations [1]. With climate change leading to both short-term disruptions and chronic stresses for societies, resilience is increasingly described as a desirable goal [2]. However, there is little research on what actually constitutes a resilient society, nor on what kinds of responsibility arrangements between societal actors are needed to achieve it.

In this paper, we operationalize and study resilience in a stylized social system using agent-based models (ABMs), and use these models to assess the effectiveness of responsibility arrangements in climate adaptation policy. ABMs allow us to represent interactions between individual entities, therefore they are better able to uncover emergent system behaviour that cannot be derived analytically from individual behaviour alone [3]. We present a first model of unequal resource and risk distribution among individuals in a community and illustrate the type of results that can be obtained on the basis of a first set of simulation runs. We use these results to determine the most promising next steps in using ABMs to represent societal agents and their interactions, and to operationalize resilience.

Approach
A first venture into representing societal responsibility arrangements and their impacts on well-being has been made with an ABM. We now describe the model's key elements.

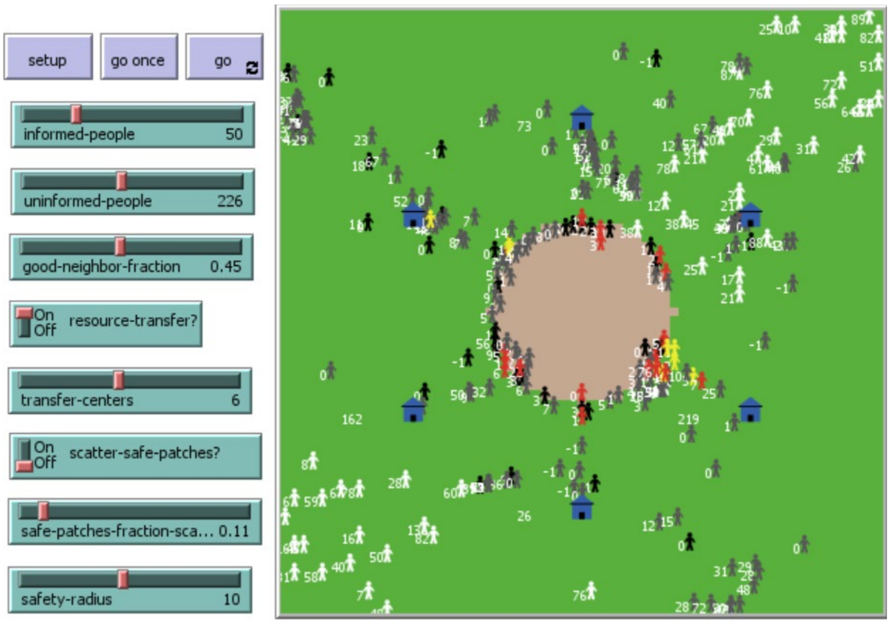

Figure 1: Snapshot of the model in NetLogo, mid-run with the central 'safe' region and the blue resource transfer 'banks'. Agents' colours reflect their states (Note: colour scheme here not related to the one used in the 'Preliminary Results' section).

Agents have resources to move to safety

The model depicts an abstract scenario with a community of individuals, each having a randomly-allocated amount of 'resources'. The community is subject to some climate change impact, and in order to keep themselves safe, individuals must move to a designated 'safe' region. Individuals must spend one unit of resource for each step they move, and when they run out, they are left stranded.

Information asymmetry

Another trait of individuals in this community is that some possess the information that they should move to safety, whereas others don't. 'Information' here may also be thought of as an abstraction of the capacity of individuals to act to keep themselves safe. An individual can start moving to the safe region only after they have been 'informed'. Some individuals are 'altruistic' or 'responsible', and will travel to some of their uninformed neighbours to inform them. Others are not and will choose to act in self-interest, heading straight to the safe region after being informed. Each step taken towards a neighbour to inform them costs people a unit of resource. Altruistic individuals will only decide to inform a neighbour if they have enough resources to be able to travel to the neighbour and then from there to the nearest safe location.

Resource banks

In addition, the model can be set up to allow transfer of resources among individuals. When this setting is 'On', the model will set up a number of 'resource banks' where those who have more resources than needed to reach safety may transfer some of that excess. Individuals who have insufficient resources to reach safety but enough to reach a resource bank will travel to the nearest one where they might receive the resources to make up their deficit. These 'resource banks' may be thought of as community institutions set up to facilitate a more equitable distribution of resources and responsibilities to improve communal well-being, which in this case is by helping more individuals lacking resources to reach safety.

Implementation

The model is implemented in NetLogo 6.1.1. It is available upon request and will be made available on the open-access repository OpenABM.

Preliminary Results

We show results from a comparative analysis of a set of simulation runs. Table 1 shows which parameters were varied.

Table 1: Model parameters and how their values were varied during runs

Experiment or model parameter	Value(s)
Resource transfer?	On / Off
# transfer banks	2, 4, 6, 8, 10
Size of safety region	5
# repetitions	500
# individuals informed at the start	Random-integer 0 to 100
# individuals without information at the start	(150 - # individuals informed at the start)
% individuals inclined to behave altruistically (inform their neighbours)	Random-integer 0% to 100%
Amount of resources per individual	Random-integer 0 to # steps needed to travel this 'world' diagonally

Figure 2 gives an overview of two sets of experiments. The plots show the number of people in different states over the course of individual model runs.

We start each run with a number of already-informed individuals, represented by the **gray** lines, and uninformed individuals, represented by the **black** ones. During each run, altruistic individuals will inform their neighbours while the rest will behave 'selfishly' and head straight to the safe region. In general all individuals will attempt to reach the safe region, resources permitting. The **green** and **blue** lines represent individuals who were able to reach safety, initially having started off being already informed (green) and uninformed (blue) respectively. These represent desirable outcomes. The **orange** and **red** lines show individuals who ran out of resources and were thus stranded in the unsafe region, again initially having started informed (orange) and uninformed (red) respectively. These represent undesirable outcomes.

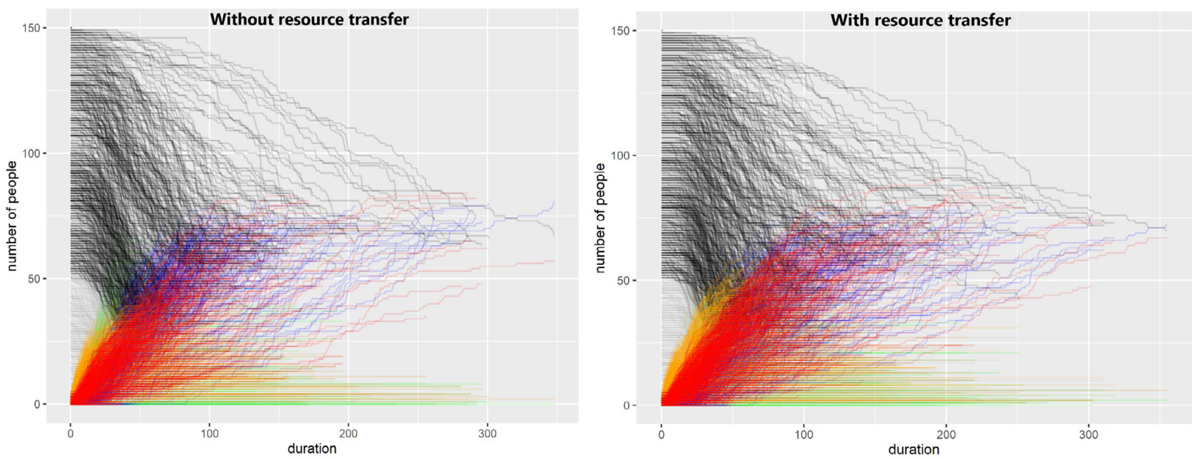

Figure 2. Preliminary simulation results. Left: Resource transfer off. Right: Resource transfer on. Colours indicate peoples' states: **black** = uninformed, **gray** = informed, **green** and **blue** = safe, **orange** and **red** = unsafe.

There are subtle effects to note in the two sets of results. One might expect that allowing resource transfer would enable more individuals to reach the safe region than by not allowing it. After all, those who have insufficient resources may travel to the nearest resource bank to secure the amount they need. However, we find that the number of individuals reaching safety is not very different between the two scenarios, and is in fact generally lower for the former.

This result is explained as follows. In the setup without resource transfer, altruistic individuals lacking resources to themselves reach safety will still travel to inform some of their neighbours. Despite themselves having no hope of reaching safety, they will contribute to other individuals reaching safety. When resource transfer is allowed, however, they are inclined to travel to the nearest resource bank to receive additional resources instead. This slows down information transfer to uninformed individuals, which appears to outweigh the benefits of enabling resource transfer – under our assumptions with respect to the number and locations of banks, the distribution of information, and the behavioural choices of agents.

Conclusion

These results have implications for the role of community institutions, especially how they may intend to improve communal well-being, but end up being inefficient and falling short as they may influence individual choices and behaviour in subtle and unintentionally societally-counterproductive ways.

The next steps include developing representations of relevant social and infrastructure systems and their interdependencies in the model. Institutions and their roles may be represented using insights developed from Ostrom's ADICO analysis [4]. A crucial goal is to develop indicators that will allow us to identify resilient and socially just states when responsibility arrangements for climate change adaptation are enacted. We intend to try to operationalize a capability approach in order to develop these indicators [5], taking into account the states and performance levels of social and infrastructure systems. Resilient and socially just states may then be defined as those in which the indicator values for each individual are all above a certain threshold value deemed acceptable for that measure.

Subsequent agent-based models will aim to incorporate these elements. Such models may then be equipped to trace out the evolution and outcomes of different responsibility arrangements in climate adaptation policy, and to identify the kinds that are more likely to lead to resilience and social justice.

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Resilience of Complex Sociotechnical Systems: Conceptualisation and Formalisation for the Air Transport System

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Summary

For complex sociotechnical systems (STS) such as airports, resilience is related to the efficient handling of unexpected adverse events. It is enabled by adaptation, which is a set of modifications within the system before, during, or after the occurrence of adversity to maintain the system's performance indicators at a desirable level. We propose a framework for STS resilience that can be formalised where humans are placed in the core. This framework can be used to conduct quantitative studies about the effects of local adaptation on global system's behaviour, in particular studies using computational modelling and simulations.

Keywords Sociotechnical systems; resilience; adaptation; conceptual framework; formal framework

Introduction

More and more unexpected events occur due to the increasing complexity of airports and their environments. Moreover, growing traffic makes airports saturated (EUROCONTROL, 2018) and consequently very brittle (Filar, 2001). It is of importance to study airports' resilience to understand how such systems can efficiently handle unexpected adverse events.

In the literature, resilience is often understood as a fast system recovery after a disruption. One famous approach is the resilience triangle metric (Bruneau, 2003). However, for complex STS where safety is essential, resilience cannot be considered only as an efficient recovery process. Some indicators related to safety risk, such as the number of casualties, or the number of accidents and incidents, must always be maintained low.

Complex STS are large systems where human and technology interact within an organisation. The role and consequences of adaptive mechanisms and adaptation, required to exhibit resilient behaviour, are not yet understood in particular because of many emergent properties. Moreover, STS resilience is problem-solving oriented so humans play an important role. For such systems, we propose a coherent formalisable framework integrating humans in its core to quantitatively study the effects of local adaptation and adaptive capacity mechanisms.

The framework is presented as followed. We first introduce performance indicators and unexpected adverse events. Second, we explain what is adaptation and how it is formalised. Finally, we present what is required for performing adaptions, namely the adaptive capacity, and how this is formalised.

1 Performance Indicators, Unexpected Adverse Events, and Their Relationship

STS resilience assumes maintaining performance indicators (PIs) within the envelope of desired performance level while undergoing unexpected adverse events. Thus, there are two main concepts that are interrelated to study resilience: performance indicators and unexpected adverse events.

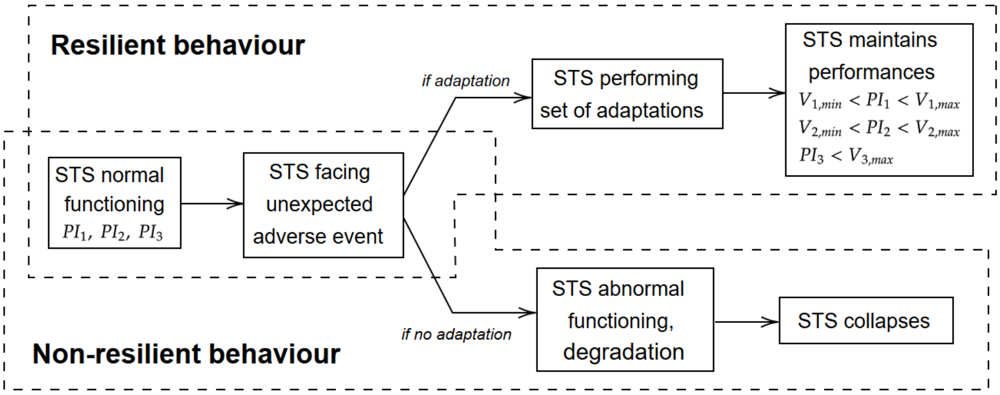

Figure 1: Relationships between performance indicators PIs, unexpected adverse event, and adaptation for sociotechnical systems (STS).

1.1 Performance indicators

Performance indicators (PIs) are defined as "a set of measures that can be used to monitor and manage a system, giving indications of the current state of the operations and supporting improvement work" (Andersson Granberg, 2013). They can be related to costs, throughput, achieved goals, utility, safety risk, among others. Examples of PIs for airports are: number of aircraft landing per unit of time, number of passengers missing their flight per unit of time, taxi time from gate to runway, number of safety incidents, amount of fuel consumption per unit of time. Figure 2 shows a typical example of evolution of three performance indicators. For PI_1 and PI_2 the envelopes of desired performance level (minimum and maximum acceptable limit values V_{min} and V_{max}) are represented. For PI_3 the maximum acceptable limit value is represented. A such indicator can represent a safety risk indicator, for example the number of casualties, or the number of accidents and incidents. PIs are easily formalisable since many of them are already metrics: they are quantitative values with associated units.

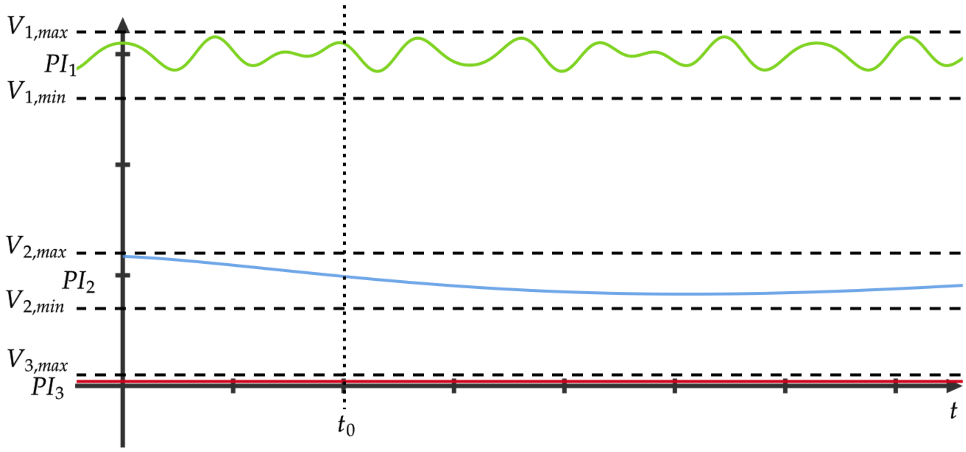

Figure 2: Example of time evolution of performance indicators, t_0 represents the time of occurrence of an unexpected adverse event.

1.2 Unexpected adverse events

Adverse events can be understood as anything that impacts or may impact the functioning of a system undesirably. In literature they have numerous names such as disturbances, disruptions, perturbations, hazards, accidents, undesired events. Some adverse events are unexpected. There are situations never encountered previously, or, if encountered, the appropriate responses were not learned. It is uncertain when and where they can occur. The formalisation of a multi-agent model for modelling a large diversity of adverse events in aviation has been done by Bosse et al. (2013).

STS resilience is related to how evolve PIs in case of ongoing unexpected events. If the system can maintain its PIs within normal or desirable performance levels, it will exhibit a resilient behaviour. This is made possible due to system's adaptation. The relationships between these concepts are presented in Figure 1.

2 Sociotechnical Systems Adaptation

STS belongs to the class of Complex Adaptive Systems because they can modify their functioning depending on situations (Dalpiaz, 2013). If the system is facing an unexpected situation, it has to adapt to the new situation otherwise it will degrade and eventually collapse (Figure 1). An adaptation is a modification of the system or any of its parts as a reaction to a potential, occurring, or occurred unexpected adverse event. Anything in the system can be modified: plans, schedules, human behaviour, tasks, roles, resources or way to use of resources, way and means of coordination, norms, among other. Modifications can be performed at any system's level: individual, social, and organisational. The process of adaptation that a human or a group of humans follow is described in Figure 3. The four sub-processes observation, prediction of a potential adverse event, identification of an occurring adverse event, and decision making are cognitive processes. This is explained due to the unknown nature of the adverse events: no automatic response can address an unknown situation thus intelligence and more generally cognitive capabilities are required.

We classify all possible adaptation in two categories: anticipation and responding. An anticipation is an adaptation that is performed before the occurrence of the adverse events, due to the perception of early signals. Anticipation in the context of STS resilience has been formalised by Blok et al. (2018) using a formal language that is able to represent spatial, temporal, quantitative, qualitative, and stochastic properties called Temporal Trace Language (Sharpanskykh, 2010). Responding is the process of adaptation that is performed during or after the occurrence of an adverse event. Formalisation of responding is done in particular by the field of re-organisation and self-reorganisation in multi-agent systems (Kota, 2012).

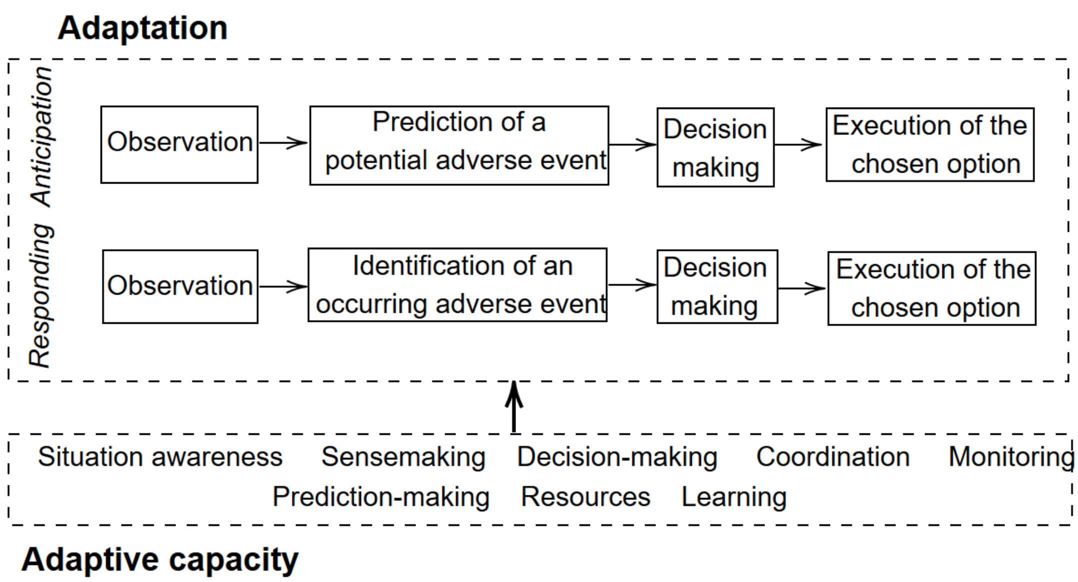

Figure 3: Anticipation and responding as the two processes for adaptation, enabled by the multiple adaptive capacity mechanisms.

3 Adaptive capacity

Adaptation is made possible due to a set of mechanisms and properties that constitutes the system's adaptive capacity. They are, among other, situation awareness, sensemaking, decision making, monitoring, coordination, resources (Figure 3). They are mainly human capabilities because this is the human part of the STS that performs adaptation. For three of them, we shortly describe their role and how they are formalised.

Situation awareness, conceptualised by Endlsey (1995) originally for the aviation domain, is an internalized mental model of the current situation of one's environment. It consists of a perception of the elements in the environment within a volume of time and space, the understanding of their meaning and the projection of their status in the near future. Situation awareness has been formalised by Blom et al. (2015) using the set theory and the vector representation to describe internal states.

Sensemaking is a cognitive process for constructing a meaningful and functional representation of some aspects of the world (Lebiere, 2013). It is based on active seeking and the processing of information to achieve comprehension in particular for abnormal situations. An example of formalisation has been done by Smart et al. (2012). They developed a formal model for team sensemaking using network theory where each agent's cognitive state such as beliefs, opinions, and attitudes is modelled and all agents are connected in a communication network.

Coordination is required in STS when several agents have to perform distributed tasks. Coordination is the management of interdependencies to achieve common goals (Boos, 2011). Formal models of coordination for multiagent planning and scheduling in organisational systems have been developed, such as ANTE and JaCaMo (Aldewereld, 2016).

Conclusion and future work

We shortly introduced a conceptual yet formalisable framework for STS where safety plays an important role such as the air transport system. We showed that STS resilient behaviour is achieved by means of adaptation enabled by adaptive capacity mechanisms. The first steps of the formalisation of different parts of the framework is introduced. It is possible to continue the formalisation in a unified theory by using formal languages such as TTL. This language can formally represent the dynamic properties of agent-based systems. Moreover, the authors currently develop case studies to investigate quantitatively the effects of local adaptation and adaptive mechanisms on the global system behaviour. We believe that this approach will enable a deeper understanding of STS resilience and will later allow practitioners to increase the real-world air transport system resilience.

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B. w3.
AI and Data-driven Frameworks for Urban Resilience

Train wheel damage detection based on deep learning

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Summary

The train wheel flat is one of the most common damages in the railway system. It occurs when a wheel locks up while the train is moving. The early detection of wheel-flat severity is crucial for passenger comfort and the safety of the railway operation. However, it is still challenging to quantify the properties of wheel flats (e.g., sizes) without interrupting the operations. One way is to transform this damage detection task into a model updating (parameter identification) task. In this abstract, a deep-learning approach is adopted to solve this inverse problem. It has been successfully applied to a field train track test in Singapore. The identified damage size obtained is consistent with on-site measurements.

Keywords

Damage quantification; Deep learning; Train wheel flat;

Introduction

As a part of the public transport systems, the urban rail system plays an essential role in urban development. Today, 55% of the world's population lives in urban areas. According to the 2018 Revision of World Urbanization Prospects (United Nations Department of Economic and Social Affairs 2018), the proportion will increase to 68% by 2050. There is significant pressure on the urban rail system. Take Singapore for example, in 2018, an average of approximately 3.3 million passengers a day used the MRT. To provide a reliable railway service to passengers, the early detection of severe wheel defects is essential for passenger comfort and railway operation safety.

The train wheel flat is one of the most common damages in the train-track system. It occurs when a wheel 'locks up' while the train is moving. Railway organizations have specified the removal criteria for wheelsets either based on the size of the flat spots or the maximum impact force or both. Due to the difficulty of measuring the wheel flats directly without interrupting the railway operation, indirect measurements are usually adopted. Various monitoring systems detect the occurrence of wheel flats through other measurements, e.g., rail deflection and rail-seat force.

In most practice, monitoring systems only provide an alert when the damage reaches the removal criteria. Once detected, the wheelsets are usually required to be replaced either immediately or within 24 hours. However, with the increase of population and urbanization, decision makers are facing more complicated situations when pursuing both efficiency and the reliability of the train operations. To provide more flexibility to decision makers, it requires quantitative information about the size of wheel flats.

A model-updating technique has been proposed to tackle this challenge (Cao et al. 2019). The unknown properties of wheel flats are built-in as parameters in the finite element models of the train-track system. The damage detection task is then transformed into a model updating (parameter identification) task. Cao et al. (2019) used a model-falsification approach to quantify the flat size. Zhang (2016) used an improved genetic algorithm utilizing migration and artificial election genetic (iGAMAS) to identify the wheel flat. The estimation of wheel flat size and impact position is treated as an optimization problem, with the best solution that minimizes the difference between the measured and estimated rail pad force responses. In this abstract, another approach that is based on deep learning is explored to solve this inverse problem.

Case Study

In Singapore, a field test is carried out at a test track in a train depot (Figure 1). Ten multilayered sensors, which are invented by Zhang et al. (2018) are installed on five consecutive sleepers. A train with 12 bogies ran on the track at 50 km/h. These rail pad sensors (RPS) measure the forces induced by the moving wheels on the rail pads. For more information on the test, please refer to the previous work (Cao et al. 2019). In this test, the wheel with the flat was running on the left rail track. Among the five sensors, only sensor RPS1 and RPS2 are functioning well. As a result, the measurements recorded by them are used for wheel flat quantification.

Figure 1: Photo of the tested rail track (Cao et al. 2019)

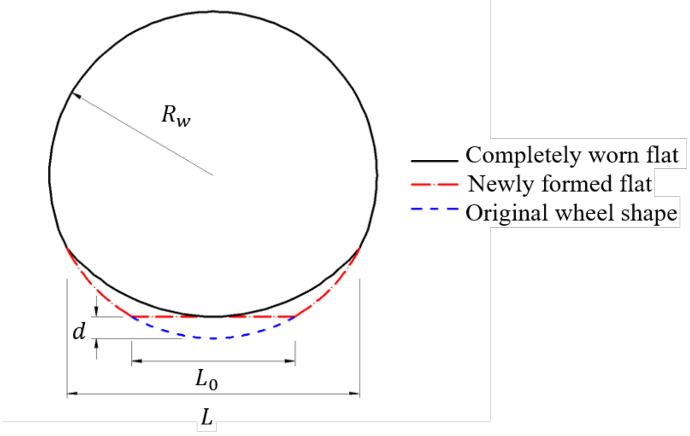

Figure 2: Schematic drawing of wheel flat (Cao et al. 2019)

In modeling the train-track system, the Timoshenko-Rayleigh beam model is used to simulate the rail, and the standard Kelvin contact-point model is adopted to simulate the rail fastening system and the sleeper support. The detailed information of the system modeling, please refer to the previous work (Cao et al. 2019). Two well-known experiments (Newton and Clark 1979; Zhai et al. 2001) have been repeated using this model. It is shown that the simulated force using this model agrees well with the measured data (Zhang 2016). The unknown parameters to identify in this case study include the length (L), depth (d) of the flat (Figure 2), the control parameter c of the wheel center trajectory, and Xp which is the location where the wheel flat hits the rail.

The verified model is used to generate datasets for deep learning. Each dataset includes the simulated response of the rail pad sensors and the parameter values. In this case study, 4000 datasets are studied in the training phase; 1000 datasets are used for validation purposes. The loss function used is the mean squared error. Convolutional Neural Network (CNN) is used to extract features from the signals automatically.

Three different cases have been investigated. Case 1 uses the simulated rail pad force at RPS1. Case 2 uses the simulated rail pad force at RPS2. Case 3 uses both RPS1 and RPS2's signals. The convergence loss of training and validation data sets is shown in Figure 3. Among the three cases, the loss in Case 3 is the lowest. It indicates that using both RPS1 and RPS2's signals is better than using only one sensor.

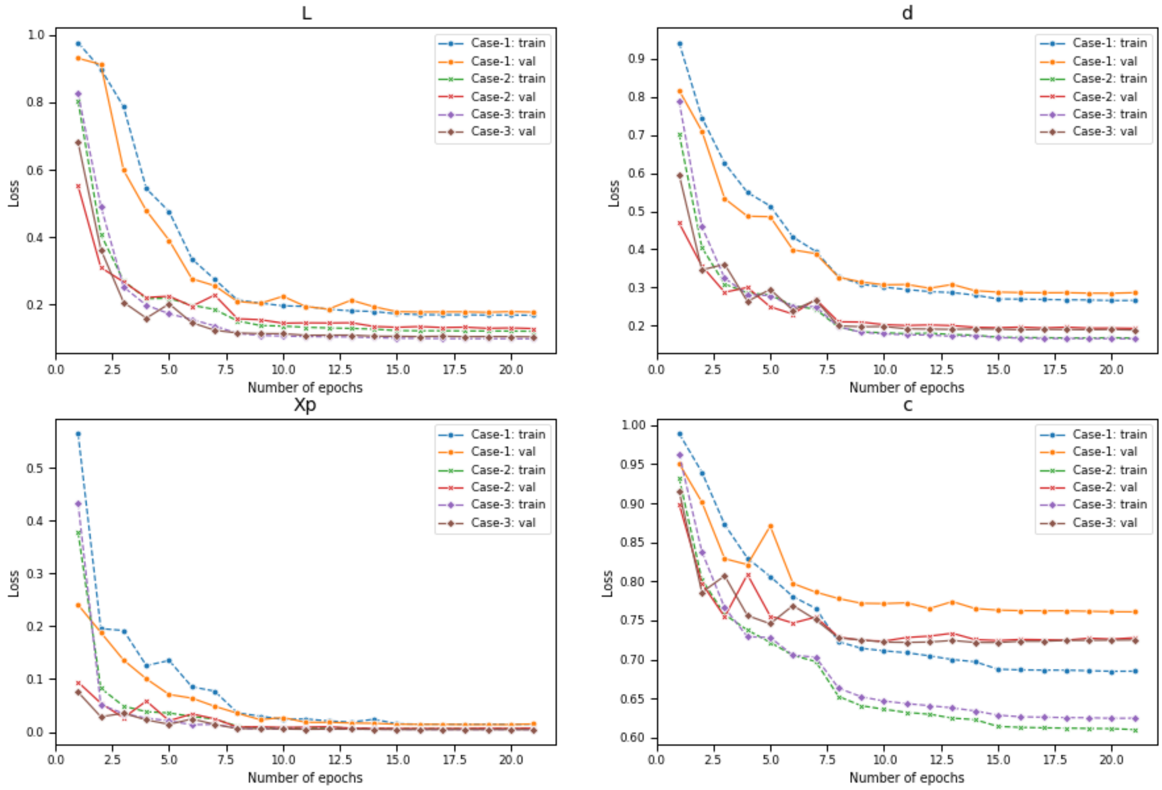

Figure 2: Convergence of loss of training and validation data sets

Using the measured signal of RPS1 and RPS2 obtained from the test, the identified depth of the wheel flat (given by CNN) *d* = 0.44mm. L_0 is further calculated by $L_0 = \sqrt{8dR_W}$ = 37.5mm. R_W is the wheel radius. To validate the identification result, L_0 was also measured on site with a measuring tape. It is estimated to be in the range of (30mm, 60mm). The predicted L_0 is within the range of the measured L_0.

Conclusion

This paper focuses on the quantification of the wheel flat's size using model updating (parameter identification) approach. Deep learning is adopted in solving this inverse problem. This approach has been successfully applied to a case study in Singapore. The identified size of wheel flats has been verified by on-site measurements.

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Risk-informed Digital Twin of Smart Buildings and Infrastructures

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Summary

The Digital Twin (DT) is a virtual replica of buildings, processes, structures, people, systems created and maintained in order to answer questions about its physical part, the Physical Twin (PT). In the case of the built environment, the PT is represented by the smart buildings and infrastructures. Full synchronization between the DT and the PT provides a perpetual learning process and updating between the two twins. In this paper we discuss a novel concept of DT, called Risk-informed Digital Twin (RDT). In the DT typically the model predictions are developed through data-driven tools and algorithms. However, several sources of uncertainty during the lifecycle challenge our capabilities to effectively model the performances of the systems. It follows the significance of the RDT which incorporates a novel framework of data-driven uncertainty quantification and risk analysis rooted on the information theory, including a risk-informed multi-criteria decision making system under uncertainty.

Keywords
Risk-informed digital twin; sustainable and resilient building design; data-driven uncertainty quantification and risk analysis; management under uncertainty

Introduction

Buildings and building construction sectors are responsible for 36% of global final energy consumption and approximately 40% of Green House Gas (GHG) emission (Abdellaoui & Hey 2008). About half of them originates from energy consumption related to cooling and heating of buildings; the remaining comes from: (i) construction stage, (ii) post-hazard repairs during the lifecycle of the buildings (Alibrandi & Mosalam 2019; Mosalam et al. 2018). It is expected that by 2050 the world population will double, and that two-thirds of all humanity will live in cities and the contributions of the built environment to the total Green House Gas (GHG) emissions will grow more and more. With the current levels of emission, we are heading for extreme temperature events increasing in their frequency, duration and magnitude. These can trigger in cascade further extreme events, like heat waves and wildfires, heavy rains, high water levels, flooding, etc. There is an urgent need to save building energy during their lifecycle and to reduce the GHG emissions from the built environment to avoid severe consequences of climate change: the 5th Intergovernmental Panel on Climate Change report states that to limit the rise of the average global temperature to 2 degrees, it is necessary to reduce them of 40% by 2030 and 70% by 2050 (compared to 2010). Novel sustainable structural materials, design concepts and construction processes are needed. New lifecycle multidimensional and multi-stakeholders tools under uncertainty should be ruled and included into the design codes.

This task is challenging since buildings and infrastructural systems should be modelled as systems of systems or networks of networks. However this appears today possible, in view of digital technologies, including machine learning, big data availability and high performance computing. The Digital Twin (DT) is a virtual replica of buildings, processes, structures, people, systems created and maintained in order to answer questions about its physical part, the Physical Twin (PT). In the case of the built environment, the PT is represented by the smart buildings and infrastructures. Full synchronization between the DT and the PT provides a perpetual learning process and updating between the two twins. In this paper it is discussed how the DT technology can be successfully implemented into the built environment, to increase the robustness, resilience, and sustainability of smart buildings and infrastructures. However, multiple sources of uncertainty during the lifecycle challenge our prediction capabilities in the digital world before deployment in the physical world. To this aim, in this paper we introduce the Risk-Informed Digital Twin (RDT), which implements an integrated framework of data-driven uncertainty quantification and risk analysis. Algorithms and tools are going to be collected in the opensource software *OpenAIUQ* as the joint contribution and efforts of different universities, currently Aarhus University and University of California at Berkeley.

Risk-Informed Digital Twin

The Risk-Informed Digital Twin (RDT) is a novel concept of DT where Machine Learning, AI, Internet Of Things, Uncertainty Quantification and Risk Analysis are holistically integrated in order to deploy the DT technology in the built environment. The RDT is based on the Performance Based Engineering (PBE) approach (Cornell & Krawinkler 2000, Gunay & Mosalam 2013), which is extensively used for evaluating measures of system performance meaningful to various stakeholders, e.g. monetary losses, downtime and casualties. PBE links in a natural way the system design to the desired performances. The PEER PBE methodology consists of four analyses: hazard, structural, damage and loss. But it can be used also to estimate the performance based on other criteria such as construction and maintenance costs, GHG lifecycle emission and Energy Consumption (Mosalam et al. 2018, Alibrandi & Mosalam 2019). PBE approach has several advantages: (*i*) it is based on elementary total probability theorem, thus easily adopted and interpreted in practice, (*ii*) it is already applied for the evaluation of the safety of structures subjected to seismic hazard by practicing engineers, making the extension to other hazards and other performances (e.g., under service conditions) straightforward, and (*iii*) the different stages of the analysis can be performed by separate groups of multi-disciplinary research teams.

In (Alibrandi & Mosalam 2017) PBE is applied for sustainable and resilient building design and implemented through the framework of Bayesian Networks (BN) (Nelsen & Jensen 2009). The BNs are graphical probabilistic models that facilitate efficient representation of the dependence among random variables. They are based on the Bayes' rule and the Bayesian inference, such that the network is updated in real-time when new information (e.g. from a network of sensors) is acquired. For this reason, they fit in a natural way inside a DT technology. The conditional probabilities are evaluated through the tools of structural reliability, stochastic dynamics and machine learning (Alibrandi & Mosalam 2018, 2019)

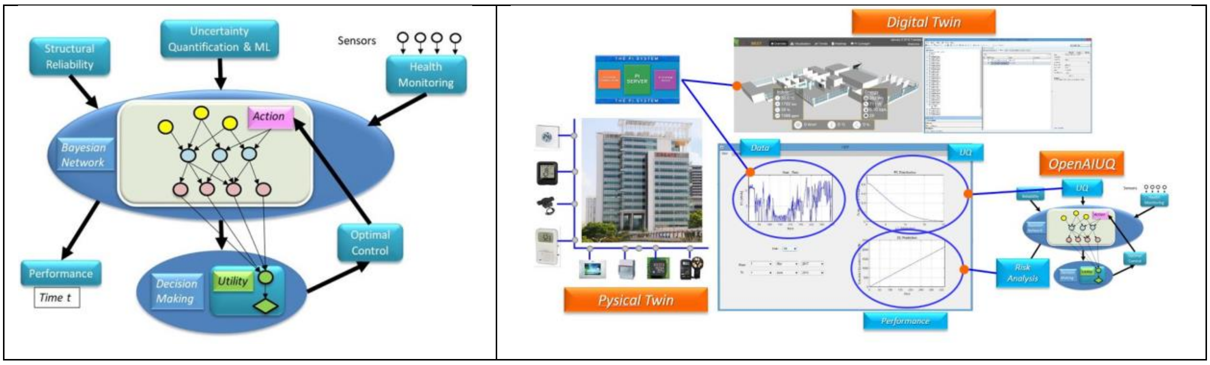

Figure 1. (a): Risk-Informed Digital Twin (RDT), computational platform, (b): implementation of the RDT into a smart building in CREATE Office, Singapore

In Figure 1(a), it is shown a schematic of the RDT presenting the following main submodules: (i) Uncertainty Quantification (UQ) and Machine Learning (ML), (ii) structural reliability and risk analysis, (iii) data-driven structural health monitoring (SHM), (iv) multi criteria decision making under uncertainty, (v) optimal control.

In Figure 1(b) it is shown a preliminary version of the RDT deployed into the SinBerBEST Office, located in CREATE Tower, Singapore. In the smart building there is a network of sensors which allows to monitor in real-time the parameters of interest, like the energy consumption, temperature, humidity, floor acceleration, etc. The smart building is the Physical Twin. The data are saved in a Process Information (PI) server, which is a real-time data application developed by OsiSoft. The DT reads in real-time the data of energy consumption from the PI server. The module of data-driven UQ evaluates the optimal distribution fitting the available data. The module of data-driven risk analysis and random vibrations predicts the lifecycle performances (here an year) of the energy consumption of the occupants of the office

The module of multi-criteria decision making under uncertainty may be used for: (i) optimal design in early stages, (ii) managements of the building/infrastructure under uncertainty. In the digital world several design alternatives (or actions during the lifecyle) are explored in the digital world, and the multidimensional consequences analyzed. In this way, a risk-informed decision can be later deployed I the physical world.

In figure 2 it is shown the application of the RDT for sustainable optimal design. In early design stage, two different energy plans are considered: (i) electricity only, (ii) PV panels and electricity. The two alternatives are compared with respect to three different criteria: GHG emission, energy expenditure and cost (installation and replacement).

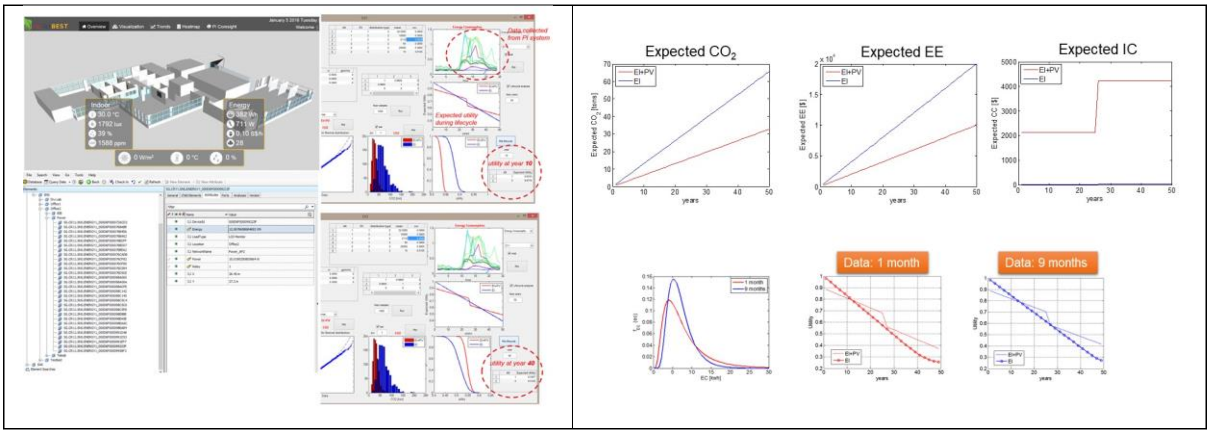

Figure 2. Application of the RDT for sustainable building design: comparison of two different energy plans with respect to three different criteria: GHG emission, Energy Expenditure, Cost

In Figure 2 the expected values of the three performances during a horizon time of 50 years are shown (panel right top), together with their expected utility. The results show that considering a lifecycle of 50 years, the hybrid solution provides greater utility. It is also shown how through Bayesian analysis the performances are updated when new information (here represented by the consumption of the occupants of the office during an year) is available, and accordingly the optimal decision.

Conclusions

In this abstract it is discussed the Risk-Informed Digital Twin (RDT) and its deployment for sustainable and resilient building design. The RDT is a Digital Twin technology where tools and algorithms of data-driven uncertainty quantification and risk analysis are implemented. They are going to be collected in the python-based opensource software OpenAIUQ. The application of the RDT to an application example has been shown

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Topic Analysis and Horizon Scanning as Proxies for Identifying Community Behavior

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Policy makers have been stressing for decades the need to go beyond the GDP when analyzing the community's progress. Different multidimensional metrics are created every year, and most recently we can see that well-being has become a fundamental feature in evaluating this progress. However, such a subjective indicator is not a trivial task. Well-being depends on social-cultural expectations and should not be treated as one equation that fits all. Few studies try to solve this problem by personalized assessments that only contemplate a very small and specific group. This study presents a framework to obtain a scalable and personalized method for evaluating subjective community-based metrics on the own community's perceptions. This research consists of two analyses wherein both cases: *cities* represent the community unit and *news articles* are a proxy for the community's perceptions. The first study will evaluate how events impact on the community's perception of the world. We use a quantitative method to calculate the intensity called Topic Resilience, a concept derived from materials engineering that is here being applied in text analysis. The second will use the city's perceptions to create a new metric, the City Identity Index. The index shows the city's main interests and therefore, the personalized aspects that they value the most given their social-cultural context. The results show how different cities have very different perspectives towards the same events and how they can value distinct aspects even when located geographically close. We believe this framework can be used in detecting and assessing emerging trends, threats, and opportunities and in guiding decision and policy-making ahead of actual events.

B. Modelling complex and interdependent STE systems
B.w4. Resilience futures challenge - battle of methods

A Survey about Resilience in Communication Networks

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Summary
This paper provides an in-depth review and discussion about the available literature on resilience in Information and Communications Technologies (ICT). We provide a brief overview of the various domains in which resilience has been studied (social, ecological, engineering, infrastructure, computing and ICT). Then we take a closer look at various dimensions of resilience in ICT (linguistic, hierarchical, challenge, a.o.). We conclude with guidelines for working on resilience in ICT.

Keywords
Resilience; Information and Communication Technologies; Robustness; Fault Tolerance

Introduction

The concept of resilience has gained attention in a growing number of research fields like economics, social sciences, engineering and ecology over the past decades. A number of significant literature surveys have been written around the topic of resilience in these domains (Bhamra et al., 2011; Yodo et al. 2016, Martin-Breen et al., 2011, Van Breda 2001).

In the Information and Communications Technologies domain (ICT), even though the number of publications related to resilience increased notably over the past few years as well, a common understanding of what resilience means and how it is measured is still lacking. Resilience as a buzzword or ambiguous use of terms such as robustness or fault tolerance leads to misinterpretations of goals (Bishop et al., 2011; Henry et al., 2012) and differing metrics for quantifying results (Hosseini et al., 2016), making it hard to compare the merits of different approaches and results.

This paper will provide an in-depth review of the available literature about resilience in ICT, identify key concepts, unify their definitions – sometimes reaching out to literature in other domains – and structure them along the various dimensions of resilience in ICT, with the goal to provide a basis that allows for ICT engineers and scientists to analyze and design resilient ICT systems around commonly understood rules.

Domains of Resilience

The term resilience originates from the Latin word "resilire" and literally expresses the action of jumping back or recoiling (Webster's Dictionary), which implies an elastic deformation primarily. In many current-day uses, however, resilience also includes the ability to withstand or simply to absorb shocks (Hosseini et al., 2016), thus implying a plastic deformative attribute as well. Hence, we may perhaps state in very general terms, that resilience has to do with an ability of a system, regardless its nature, to reach an acceptable operational point within admissible state-space boundaries again, after having been pushed out of those boundaries by one or more perturbations, be them internal, external or both.

An ecosystem is defined as a "complex of a community of organisms and its environment functioning as an ecological unit" (Webster's Dictionary). Consequently, *ecological resilience* refers to the persistence and capacity of a system to absorb changes and disturbances, while not changing its structure (Holling, 1996). It is to be noted that most ecological systems are not pristine but strongly influenced by human activity, which poses a particular interest in the notion of ecological resilience. The term social-ecological systems was coined accordingly (Berkes et al. 2008).

In the social domain, *social resilience* is the ability of individuals, groups and communities to cope with external stresses and disturbances that may result from social, political and environmental changes (Adger, 2000). This includes reducing the impact of events as well as adaptation to new conditions (Berkes et al., 2008) or actual system transformation when necessary (Walker et al., 2004). Resilience in this context also includes the ability to predict the risk of such events (Rose, 2009).

The concept of *engineering resilience* is relatively young and pertains to technical systems. It is strongly related to the capability of a system to provide its essential functions when facing internal or external disturbances. Conceptually, engineering resilience can be described as the sum of *reliability*, measured as the probability that a system maintains its performance above a certain level during a given amount of time ("passive survival rate") and *restoration*, measured as the degree to which reliability can be recovered after a failure ("proactive survival rate") (Youn et al., 2011). Reliability is considered in engineering an important attribute of systems (Hosseini et al., 2016).

Infrastructure systems are eminently socio-technologically interdependent, as they can be viewed as a subdomain of the engineering domain as well as of the social domain. While the social domain focuses on how infrastructure systems affect communities and enhance daily life, engineering resilience of infrastructure focuses on their construction and restoration by incorporating qualities of resilience into those processes (Hosseini et al., 2016). It is to be noted that infrastructures, the economy (Percoco, 2004) and society (Bruneau 2003) are strongly interdependent, which leads to an overlap of resilience between these domains.

Another subdomain of engineering is all that entails *computing systems*. In this subdomain, the term resilience has commonly been used as a synonym for fault tolerance, leaving out the ability to adapt to unexpected changes that a system may have to face (Laprie, 2008). Fault tolerance techniques rely on redundancy and are not sufficient a resilience tool in the face of correlated component failures (Sterbenz 2010). The denotation of resilience in computing systems shifted in time towards a notion of the persistence of dependability, i.e., the ability to deliver service that can justifiably be trusted (Avizienis et al., 2004). This notion includes a number of attributes such as reliability, availability, safety, integrity and maintainability. All these terms need careful definitions and understanding in the context of resilience.

Telecommunication networks can be viewed as both a subdomain of computing systems and of infrastructure systems, and are therefore also an example of an STE-interdependent system. As such, there are a variety of possible ways to look at resilience for these systems. Looked at as a computing system, Sterbenz et al. understand their resilience as the ability of the network to provide and maintain an acceptable level of service when subject to faults and disturbances that challenge normal operation (Sterbenz et al., 2010). As an infrastructure, to the best of our knowledge, the resilience of (tele)communication networks has not received special attention yet.

Dimensions of ICT Resilience

Resilience is a multidimensional concept. It includes dimensions such as linguistic, hierarchical and challenges, which we briefly describe in the sequel for communication networks (more dimensions will be addressed in the paper, including service level, dependence on infrastructure, temporal dimension).

Linguistic Dimension

Many concepts, such as *fault tolerance, robustness or survivability* are strongly related to resilience. They are sometimes used interchangeably and sometimes not. On the other hand, resilience is often considered an umbrella term, which includes these concepts. Other times, resilience is defined by those terms. In any case, ill-defined or imprecise use of these concepts leads to misinterpretations of goals and results (Bishop et al., 2011). A precise definition is necessary to adequately integrate them into the context of resilience.

Hierarchical Dimension

For some networks, such as wireless sensor networks, their elements or entities can be classified at the level of individual *node components* (such as sensors, actuators, power supply, motherboards, server parts, radio interfaces, discrete and integrated circuit components), the *nodes* themselves, the *network* as a whole and the complete communication *system* (Selmic et al., 2011). One important aspect to be considered in this dimension is that resilience at a given hierarchical level is dependent on the resilience of entities at lower or higher hierarchical levels. Also, redundancy and diversity of lower-level entities directly affect resilience at higher levels. Redundancy is required to cope with faulty entities by functionally replacing them. Diversity ensures that redundancies are independent in such a way that adverse events do not affect multiple instances of the same entity at the same time (Sterbenz et al., 2010).

Challenge Dimension

Another dimension comprises the different challenges that a network may have to face. They can be classified by *severity*, *duration*, *effect* or *prospect* (Sterbenz et al., 2010; Laprie 2008). While some events have no or minor impact on the functionality of a network, other events may require acts of mitigation or maintenance to recover full services. Events with a short duration, as in dynamically changing systems (e.g. ad-hoc networks), require different measures than long term events. Challenges to a network do not only differ in magnitude and severity, but they can also be clustered by their effect on the network. Different approaches are required for random node failures and targeted attacks. Also, challenges such as temporary failures or changes in traffic load have to be taken into account. Some events may be predictable, which enables system designers to prepare for them, while others cannot be foreseen. Preparing for unknown events requires strategies not commonly captured in classical risk management (Linkov et al., 2017).

Conclusion

Resilience is a very broad concept that spans numerous dimensions in various domains. There is no commonly agreed definition of resilience. Varying definitions are often incompatible and complicate work and discussions around the topic.

As a framework for ICT engineers and scientists to discuss, analyze and design resilient ICT systems, we recommend to address the following points in a timely manner:

1. Identify the scope (domain, dimensions) in which your definition of resilience acts. Provide precise linguistic definitions.
2. Define your understanding of resilience early and quantitatively. Quantitative definitions tend to be system-specific. A balance must be found so that the definition is portable from one system to another.
3. Measures of resilience must allow for comparison between similar systems and over time. Good definitions are forward-looking and remain valid as systems evolves.

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B.w4. Resilience Future Challenge – battle of methods
B. Modelling complex and interdependent STE systems

Use of Multi-Nodal Centrality to Identify Criticality in Networks

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Summary
This paper provides tools to model and evaluate nodes in a transportation network in a disaster scenario where a large number of individuals needs fast access to one of a small set of resource nodes (e.g., hospitals). We augment the origin-destination betweenness centrality metric to account for relative distances of resource destinations as well as the population density in a network. These centrality metrics are computed and compared for a hypothetical lattice network as well as the road network in Kathmandu, Nepal for randomly generated disaster scenarios. These identify critical nodes of the network that must be hardened so that the overall network remains resilient in a disaster.

Keywords
network resilience; transportation network; betweenness centrality; Nepal earthquake

Introduction
The resilience of transportation networks against disasters and modelling of these complex phenomena have been increasingly studied in recent years, partially due to road network's value for societies in our everyday lives but also because of its functions during the recovery phase after manmade or natural disasters. Whether it is for providing accessibility to everyday services or for accessibility to critical functions (i.e., hospitals, emergency management centers etc.) during the disasters, transportation networks are among the most crucial components of societies today.

There are different streams of literature on the resilience of transportation infrastructure. One focuses on the use of network science to identify important components of transportation networks by performing criticality analysis. Jafino, Kwakkel, & Verbraeck (2019) discussed a wide range of criticality metrics including those derived from network science and performed an empirical comparative analysis of the selected metrics based on transport functionality. The authors provided guidelines for selecting a suitable metric for a specific purpose. Network analysis for humanitarian logistics has also been used to analyze accessibility to communities after disasters in Warnier, Alkema, Comes, and Van de Walle (2020), for finding a best possible recovery strategy after earthquake-triggered landslides in Aydin, Duzgun, Heinimann, Wenzel, and Gnyawali (2018), to evaluate the cascading failures on tightly spatially coupled sewer and road systems in Dong, Wang, Mostafizi, and Song (2020), and to analyze resilience of New York City transportation network against Hurricane Sandy in (Ilbeigi, 2019).

Network analysis and centrality metrics clearly provide a good approximation on peoples' movements, accessibility to services and urban mobility overall, therefore has been used widely in criticality analysis of road networks. Specifically, the Betweenness Centrality (BC) of node was defined by Freeman 1977 as the fraction of the number of shortest paths that contain the node, summed over all pairs of nodes in the network. Rankings of nodes based on BC have been used in primarily topological analysis of the road network (i.e., (Casali & Heinimann, 2019; Porta et al., 2011)), but also in the context of disaster management of road networks. For example, Casali and Heinimann (2020) used BC to determine the robustness of the Zurich transportation network; BC was used in percolation theory to provide insights into spatial network characteristics under changing disruption scenarios. In addition, Çetinkaya, Alenazi, Peck, Rohrer, and Sterbenz (2015) used BC together with the other network metrics to evaluate multilevel resilience of transportation and communication networks.

Although network science and criticality metrics are easy to apply and effective in providing some insights into transportation network resilience, most of the time more in-depth analysis is required or modifications to those metrics are necessary to be able to answer disaster resilience specific questions. For example, Aydin et al. (*Computational Urban Planning and Management for Smart Cities*, 2019) modified a widely-used BC-index in order to identify changes in criticality when travelling to hospitals after the earthquake in Nepal, 2015. While the study provided crucial insights and preliminary results for this context-specific problem, the intrinsic relationship between a city's social attributes (i.e., total population) and specific services was not included in the analysis.

In the following sections, we augment the origin-destination betweenness centrality metric to account for relative distances of resource destinations as well as the population density in a network. These centrality metrics are computed and compared for a hypothetical lattice network as well as the road network in Kathmandu, Nepal for randomly generated disaster scenarios. These identify critical nodes of the network that must be hardened so that the overall network remains resilient in a disaster.

Centrality Metrics

The *Origin-Destination Betweenness Centrality (ODBC)* metric proposed by Aydin et al. is a modification of the original Betweenness Centrality metric in that shortest paths are only computed between pairs of specified origin nodes and specified destination nodes (rather than all pairs of nodes in the original BC metric); i.e., we compute *all* shortest paths for each origin-destination pair (noting that there could be many distinct shortest paths between a pair of nodes) and record the number of times each node in the network is included in these paths. The importance of a node *x* in the network is given by:

$$ODBC_x = \sum_{d=1}^{n} \sum_{o=1}^{k} \frac{n_{o,d}(x)}{n_{o,d}}$$

where *n* is the number of destinations, *k* the number of origins, $n_{o,d}(x)$ the number of shortest paths from *o* to *d* that contain node *x*, and $n_{o,d}$ the total number of shortest paths from *o* to *d.*

The *ODBC augmented by Relative Destination Distance (ODBC_RDD)* metric is used to assess a scenario with multiple destinations (e.g., such as hospitals), *only one of which will be chosen for actual travel*. We modify the definition of ODBC by weighting an origin-destination pair by the likelihood that that destination is actually selected by a user at an origin *o*. The weight associated with a destination *d* consists of computing the distance from the origin *o* to the nearest destination relative to its distance to *d*. Put simply, we will give higher weight to a path that leads to the closest hospital relative to paths leading to hospitals that are further away. The equation below specifies an additional multiplier, where $mindist_o$ represents the distance between the origin *o* and the destination closest to it, and $dist_{o,d}$ is the distance between origin *o* and destination *d*:

$$ODBCRDD_x = \sum_{d=1}^{n} \sum_{o=1}^{k} \frac{n_{o,d}(x)}{n_{o,d}} * \frac{mindist_o}{dist_{o,d}}$$

The *ODBC augmented by population metric (ODBC_POP)* considers the population along a path. Each node is assigned a population value from which a normalized population weight between 0 and 1 is derived. Node populations are used to obtain the average population on a path between each source and destination node. These are used to modify the ODBC equation as follows:

$$ODBCPOP_x = \sum_{d=1}^{n} \sum_{o=1}^{k} \frac{n_{o,d}(x)}{n_{o,d}} * p(o,d)$$

Where $p(o,d)$ is the calculated population weight between nodes *o* and *d*.

Results – Lattice Graph

A baseline computation of network metrics on an unaffected network allows us to meaningfully assess the metrics in a disrupted network. Specifically, we will compare the various betweenness centrality metrics for individual nodes before and after simulated network disruptions. Figure 1 shows baseline scenarios for four centrality metrics used on a two-dimensional lattice test network. All values have been normalized between the numbers 0 and 1 after calculating centrality results in order to better visualize and compare results. Nodes have been partitioned into 5 groups using an approximately logarithmic scale. The 0-50th, 50-75th, 75-88th, 88-95th and the 95-100th percentile nodes are colored blue, green, yellow, red, and black, respectively. The destinations (hospitals) used in Figs 1(b)-(d) are represented in orange and were randomly chosen.

Except for Figure 1(a), which is oblivious to hospital locations, all figures show higher centrality values for nodes in the vicinity of hospitals (as expected). Figures 1(b) and 1(c) show subtle differences between ODBC and ODBC_RDD metrics with a slight increase in the importance of nodes closest to hospitals relative to nodes in the center (see, for example, the band of yellow nodes in 1(b) in the center that get downgraded to blue or green in 1(c)).

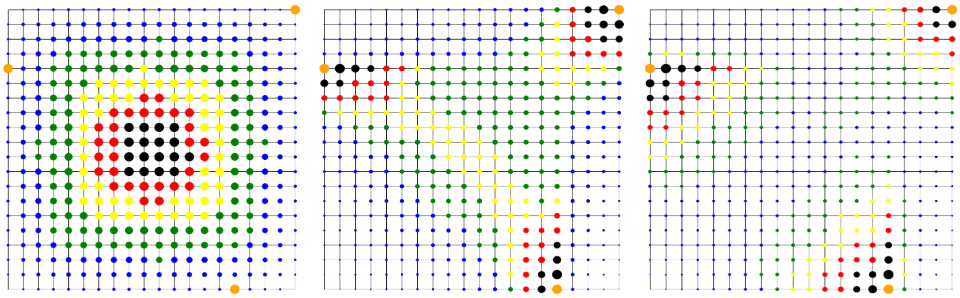

Fig. 1 Images show results of three centrality metrics on the same graph. Metrics used are: **a)** simple (all-pairs) betweenness centrality, **b)** ODBC **c)** ODBC_RDD

Results – Kathmandu Road Network with edge disruptions.

Figures 2 and 3 below depict the Kathmandu road network with 10% edge-disruption using the ODBC_RDD and ODBC_POP metrics. Each figure represents the average of 125 experiments, each of which randomly chooses 10% for deletion (to simulate a disaster). In both figures, the left image depicts the normalized ODBC values represented by node size and the differences between the original and disrupted network ODBC values. The right image classifies nodes that increased in importance in red, and those that decreased in importance purple. If there was no change, these nodes are colored gray. The node size itself represents the size of the difference between ODBC values for an unaltered and a disrupted network at the percentage referenced previously.

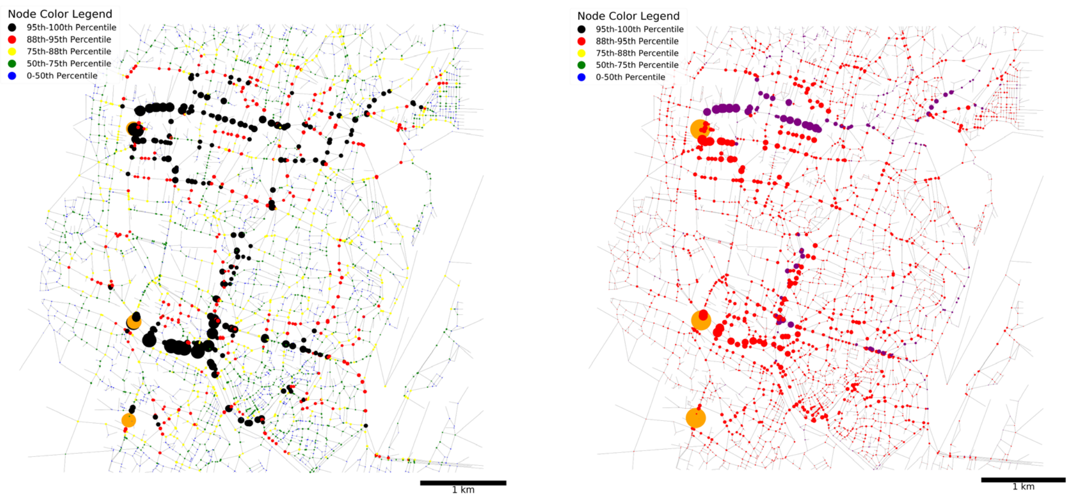

Fig. 2 ODBC_RDD with 10% edge disruption.

Details of the population computation used in Fig. 3 are omitted due to space constraints. Qualitatively, however, the population skews heavily to the left half of the catchment area. This leftward shift in the locations of important nodes is observed when comparing Figures 2 and 3.

Conclusions

This paper shows that modifying the ODBC metric of Aydin et al. (2018) to account for multiple distances, relative distances and population is necessary to evaluate and improve a network's resilience in preparation for natural or man-made disasters. Our results identify key paths needed for users to access selected resource nodes. Nodes with priority levels in the 88-95th percentile provide stakeholders with additional and less-obvious data feedback to further increase network resilience. In addition, random disruption scenarios illustrate which routes will see an increase in importance.

Applying these techniques for to assess network resilience in different regions (e.g., states in the U.S.) could provide a framework for resource allocation. Similar analyses could assess disparities in network resource accessibility between wealthy and poor neighborhoods.

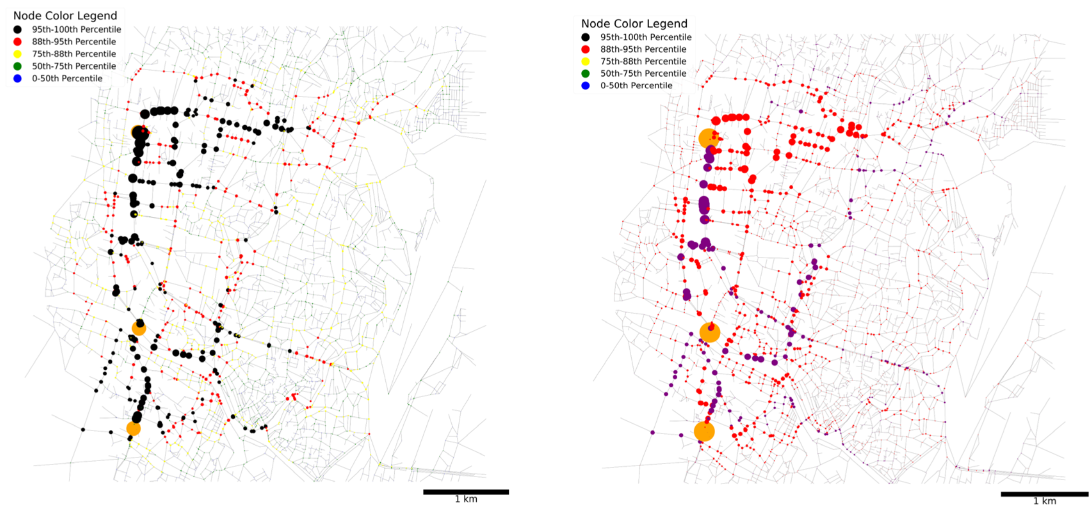

Fig. 2 ODBC_POP with 10% edge disruption.

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Multicriteria benchmarking of European electricity supply resilience: the case of interacting criteria

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Summary
The resilience of electricity supply is a complex and multidimensional concept, receiving growing attention at a European level. In particular, the increasing risks of extended electricity supply disruptions and severe electricity price fluctuations are stressing the need for an assessment of the European countries' electricity supply resilience. Towards this direction, this paper proposes an elaborative multicriteria decision support methodological framework, on the basis of three major resilience dimensions: Resist, Restabilize, Recover. In total, 35 European countries are evaluated and ranked according to their performance on 17 indicators, through a synergy of MCDA methods. The assessment framework has been extended to incorporate the Choquet Integral, in order to accommodate interacting criteria and negate their arbitrary effects on the final benchmark. The overall objective of this research work is to support energy policy decision making in Europe and provide guidelines and areas for improvement at a country level.

Keywords
Resilience; Security of electricity supply; Multicriteria decision support; Interacting criteria; Choquet integral

Modelling complex and interdependent STE systems
Resilience future challenges – battle of methods

Cost-Benefit Resilience Optimization of Critical Infrastructure – A Case Study of a Real-world Water Distribution System

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Summary
Urbanization has a strong influence on critical infrastructures. Especially on the critical infrastructure of the water distribution system since it is not only crucial for the human survival and well-being but also takes an important and limiting role for industry, agriculture and hazard fighting. Its demand pattern undergoes short and long term changes. More so in urban spaces due to the steady urbanization. Therefore, the water distribution system's resilience is of high relevance to its operators. The addressed challenge of high-quality and, at the same time, low-cost water supply is approached by a cost-benefit analysis based on a topological graph-theoretical resilience metric. Therein, the enhancement of the water distribution system by the addition of pipes is modelled in a Mixed Integer Linear Optimization Problem. The optimal enhancement of the real-world water distribution system depending on the investment costs as well as its characteristics are presented in this work.

Keywords
Water Distribution Systems; Graph Theory; Resilience; Optimization; Cost-Benefit Analysis

Introduction
Critical infrastructures face different challenges in the light of urbanization. One of these infrastructures is the water distribution system [1]. Fresh water is not only indispensable for human well-being but also for industry, agriculture, energy production and further more for combating hazards in daily life. Apart of several measures to reduce the per capita water consumption, the growth of industries, global population, and therefore farming leads to a predicted water demand increase by 30 % until the year of 2050 compared to the year 2000 [2]. At the same time the steady urbanization is predicted to continue leading to an increase of the urban population by 2.5 billion inhabitants in the same time horizon [3]. These trends lead to an increased water demand in urban areas also and to a high responsibility of the water distribution system operators to meet the water demands. The failure or reduction in meeting the respective demands limit not only residents but also can have a massive impact on critical water users in both, economy and health care [4], [5]. Therefore, not only robustness but resilience of the water distribution system is of great interest. When exposed to disruptive events, resilient systems maintain a minimum level of functionality, in the case of water distribution systems its demand fulfillment, and subsequently possibly recover from the disturbance [6]. There have been different approaches of assessing the resilience of water distribution systems [7]. In this work we focus on the graph-theoretical metrics to assess the resilience of a real world water distribution system. Graph-theoretical metrics originating from network theory have been shown to have a clear correlation to the system's resilience [8]. Therefore, the network is converted into a planar mathematical graph whose edges represent the pipes and pumps connecting source and demand nodes. Resilient networks have a robust and redundant network design [9], which can both be measured by simple or more sophisticated graph-theoretical metrics [10]. In this work we base the resilience assessment on a well-established resilience metric covering both aspects based on the water distribution system's topology [11].
To support decision-makers, this can be local water suppliers and public authority, a cost-benefit analysis is conducted in this work to address the demand for high-quality and, at the same time, low-cost water supply. Therefore, the combinatorically challenging problem of where to adapt the water distribution system is analyzed within a Mixed Integer Linear Optimization Program considering the technical feasibility of the proposed solution.

Method
To assess the resilience of a water distribution system graph-theoretical resilience metrics originating from network theory consider the pipes or pumps of the infrastructure as edges with properties as its length, diameter, roughness and flow velocity. These edges connect source and demand nodes with in- and outflow properties representing the water demand and supply as well as its pressure, respectively. Nodes and edges representing the mathematical graph are assumed to be strictly planar

which means that edges crossing each other always intersect prohibiting under- and overcrossing of pipes.
The applied graph-theoretical resilience metric assesses the topology of the network by taking into consideration the two, redundancy and robustness, which define a resilient network. First, it determines all paths connecting a demand node to each source and therefore allowing for alternative paths feeding a demand node in the case of component failures of pipes or pumps. Second, the physical feasibility of these paths is assessed and ranked by considering its hydraulic properties. For this the pressure losses in each path are taken into consideration to evaluate its practicability. The physical considerations underlying the concept of the hydraulic resistance of each path were derived in detail in [12]. Thereby also an order of magnitude analysis for the feasibility of alternative paths is given, which can then be applied to the network under consideration. The hydraulic resistance of pipes in water distribution systems depends solely on topological characteristics of the water distribution system and is therefore independent of the actual demand pattern. Therefore, the demand fulfillment can be pre-evaluated by the laws of continuity.
The effectiveness of the herein studied addition of pipes to an existing water distribution system to increase its resilience has equally been shown [12]. Since the selection of pipes added to an existing water distribution system leads to a challenging combinatorial problem, it can be solved by mathematical optimization. To study the Pareto front of a cost-benefit analysis, a Mixed Integer Linear Problem (MILP) is set up, based on the linearized resilience assessment conducted in [13]. This analysis allows to assist decision-makers to enhance the water distribution system efficiently towards a higher resilience taking into consideration the physical feasibility of the solution. This is done by considering the physical and technical limitations of the adaptation in the water distribution system by additional constraints in the MILP. These constraints are continuity of flow, limitation of the investment budget, and the present urban structure. The investment budget is assumed to be proportional to the length of pipes added to the existing water distribution system and therefore the sum of the binary decision variables for each pipe multiplied with its respective length is supposed to be less than the allowed length added. This length varies for different points making up the Pareto front. Where pipes can be added is under strict technical feasibility constraints. These are given by the present urban structure, i.e. the urban transportation system. Since infrastructures are parallel [14] and are supposed to be planned parallel [15] to the street network, the urban transportation network is restricting the adaptations to the existing water distribution system. Therefore, the maximal possible graph of the water distribution system is given by the urban structure and its street network. Out of these maximal possible adaptations the implemented optimization program chooses the addition of pipes enhancing the overall resilience of the water distribution system most.

Case Study
The method of enhancing the resilience of an existing water distribution system is applied to a real-world main line water distribution system in a district of a German city, c.f. Fig. 1. While the water distribution system's information is provided by the local water supplier, the information of the urban transportation system is extracted from Open Street Map data. The implementation is done in Python using the packages WNTR [16] and NetworkX [17] for the graph-theoretical analysis and GurobiPy [18] for the optimization. In the preprocessing first the streets under which no main lines lie are determined and then the common set of all nodes and edges either in the main line water distribution system with diameters greater than $100\ \mathrm{mm}$ or the possible additional edges in the urban transportation system is set up. These are marked by solid and dashed lines, respectively, in Fig. 1. A further step of the preprocessing is the calculation of all possible shortest paths, in which the edge weight is the hydraulic resistance of the respective pipe, depending on its diameter, roughness, and length. During the optimization process with the help of binary variables, the addition of pipes to the existing water distribution system is chosen in such a form that the now possible additional paths enhance the overall resilience of the water distribution system most. This leads to different adapted networks depending on the overall investment budget, i.e. additional pipe length considered.

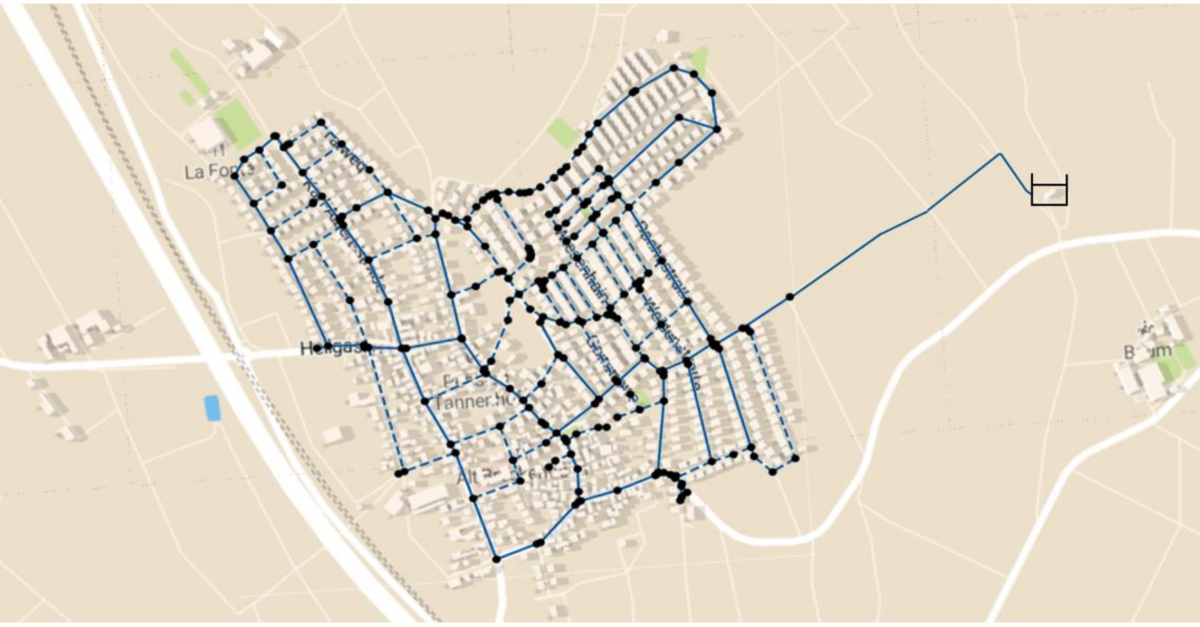

Figure 1: Existing main line water distribution system and its possible additions marked by solid and dashed lines, respectively.

Conclusion

The conducted cost-benefit analysis of a real-world main line water distribution system can support decision-makers, as water distribution system operators, by determining the locations of where to adapt the present water distribution system to increase the water distribution system resilience. Furthermore, this study showed that with increasing investment budget the resilience enhancement of the water distribution system converged due to the given urban structure in which the water distribution system is situated.

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Corona's lesson to the world: the need for resilience

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Summary

The climate crisis, resource shortages, social fracturing, economic disparities, natural disasters, and other events have given us plenty of reasons to want to steer society in a different direction. For years, we've seen different theories on how to best do this. Climate adaptation, the circular economy, transition theory, the bio-based economy, and other approaches compete for the same space and attention. Despite their important role and message, they are only part of the solution. As a virus outbreak suddenly brings the world to its knees, our priorities have become clear, and one approach stands out like a lighthouse in the mist: resilience. In this article, we explore how the concept of resilience is relevant to the Corona crisis, and exemplify a practical framework for the application of resilience in the practice of policy, planning, and industrial production through the Symbiosis in Development (SiD) framework.

Resilience; efficiency; systems thinking; COVID-19; systems theory

Introduction

We live in an increasingly fragile world, with growing inter-dependencies, and blooming uncertainties. In a time where uncertainty reigns, resilience focuses on our capacity to deal with the unexpected. It should be underpinning everything we do, from policymaking to city planning, from industrial production to healthcare management. The next big challenge may blindside us as much as this virus did; we simply do not know what the future holds. Only increased resilience — in our cities, countries, and global society — helps us face our uncertain future. We could be 100% circular, or climate-adapted, but if we're not resilient to the unexpected, the next systemic global event will topple us over just as well.

Resilience isn't a new concept. It's not a branded ideology, not an AI software tool, or a guru-driven belief. It is a scientific, analytical concept, that determines the 'survivability' of a system. The concept of societal resilience has been around since the '60s and is a well-proven and documented field. In the last decade, it has taken off. The best way to understand it is through complex systems analysis.

Resilience can be broken down into sub-components — such as connectivity, transparency, efficiency, and diversity — to better understand how parts of a system affect and interact with each other. There are experts all over the world devoted to complex systems thinking. Their tools, such as system-network hierarchy and causal loop mapping, can be applied to measure resilience. The open-source framework Symbiosis in Development (SiD) is a good starting point to work with the concept, as explained below.

Figure 1: Resilience is broken down into 9 core parameters in the Symbiosis in Development (SiD) framework.

A framework for systems thinking, SiD encompasses theoretical concepts such as the circular economy and methodologies like design thinking with hands-on tools to map out systems, networks, and objects. The framework's explicit methodology was designed to assist in co-creation processes.

The clash between efficiency and resilience

Understanding the different layers of resilience may be intimidating at first, but the truth is that it is used every day by architects, managers, policymakers, scientists, and engineers around the world. In fact, by looking at exponential curves on COVID-19 cases every day, and diagrams on intensive care bed distribution and such, we are all now more familiar with the level of abstraction where resilience plays out than ever. For better or worse, corona provides the perfect exemplary case for planning for resilience.

For example, Germany has 32 IC beds per 100,000 inhabitants. The Netherlands has 8. While Germany was criticized by the OECD last year for being 'inefficient', this is now an enormous blessing for Germany and the Netherlands. More than 100 Dutch people were treated in an IC in Germany at the peak of the outbreak. A wonderful case that exposes one of the core fallacies of neo-liberal management that dominated the last 30 years. It does not take societal resilience into account but mostly focuses on efficiency. 'Efficiency' is a systemic network parameter of resilience that seeks an optimum, not a maximum. Maximize efficiency, and your resilience collapses. This is what happened in the Dutch healthcare system (and others). The Dutch drive for 'efficiency' at the expense of its total resilience has failed its healthcare system and the citizens that depend on it.

In the SiD framework, resilience is related to Autonomy and Harmony on a systems level. Together they present a series of network parameters that can be tested in a qualitative as well as a quantitative sense. With this framework, a measuring system can be designed within context for individual projects or cases, that is still related to the general concept. This practical approach merges the needs to be both thorough and practical at the same time.

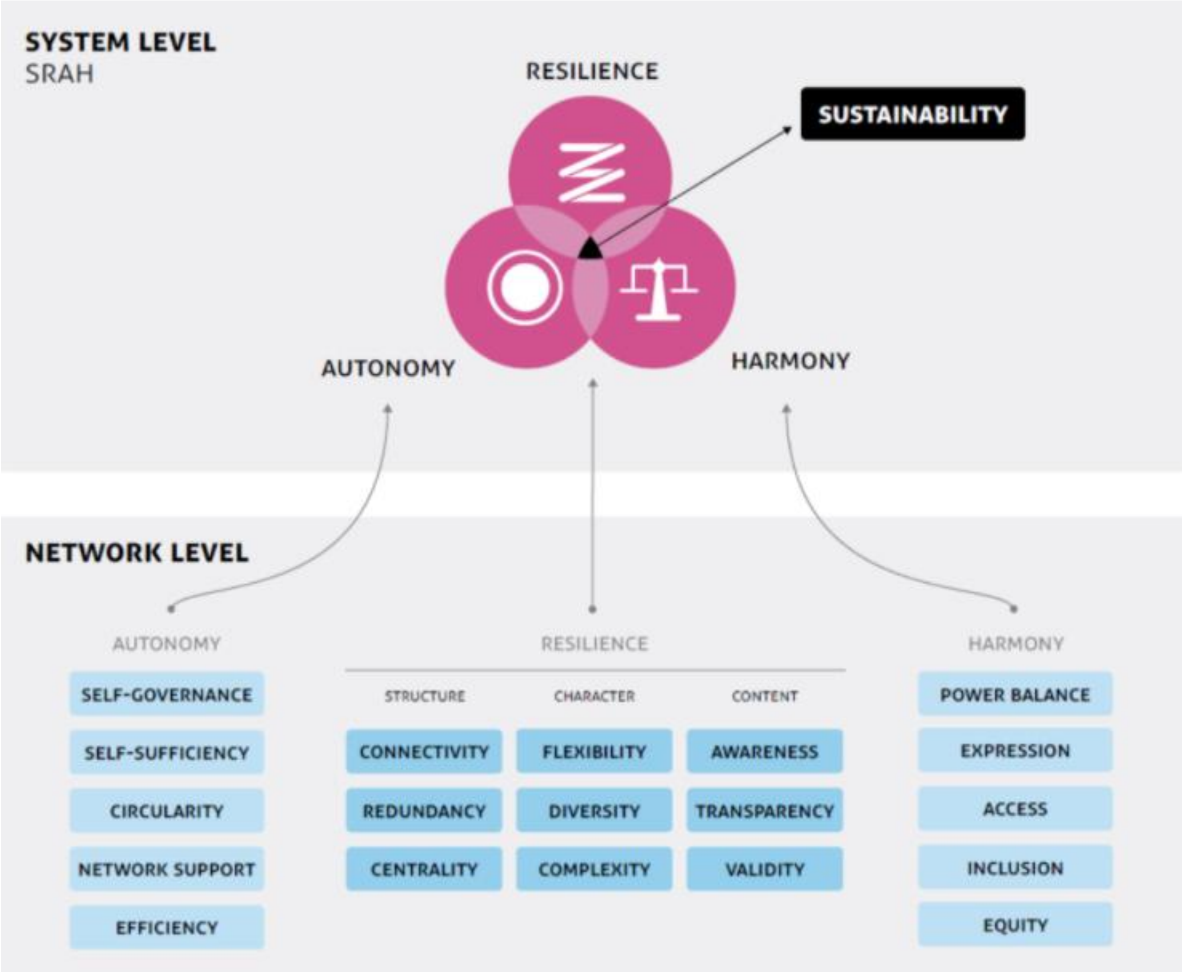

Figure 2: the SiD systems and network level evaluation framework for complex systems.

It is interesting to consider the drive for efficiency in the context of rising sea levels in the low-lying country. While the Netherlands has historically focused on efficiency, which in this case means putting up the highest 'dijken', the awareness for resilience started to crystallize in recent years. As a result, 'waterschappen' (water authorities) start to implement a mixed method of fortified infrastructure and nature-based solutions like stretching wetlands.

Examples of maximizing efficiency while compromising resilience are everywhere you look, from how we plan our cities, to food production, energy, essential supply chains, education, health, and related policies. Consider one of the most widespread agricultural practices of today: monoculture farming. While crops grown this way yield high results and care is linearly scaled, they are also prone to pests and, in the long run, reduce soil fertility (perpetually increasing the necessity for inputs).

Systemic foundations of a resilient society

The interesting thing about integrating resilience as a key measure is that aspects such as the circular economy and climate adaptation come in through a side door in the process of resilience analysis. However, this time, they are placed in relation to each other, and it is possible to indicate priorities between them. This means that resilience is a higher-level, overarching concept that can be used to manage layers beneath it, analyze, relate and evaluate them, and figure out concrete steps towards improvement.

Circular economy and climate adaptation are sides of the same coin, illustrated when looking at systems holistically on the most basic level. After all, an increase in the use of recycled plastic derivatives would serve both goals. Energy & Materials, Life, Society, and the Individual (ELSI) within it are all connected, and combined for a framework tool that can be used to verify holistic thinking. ELSI is a categorizing tool that allows us to map out the functionalities of any physical object, consequently showing causal relationships among a network of objects. Circularity focuses primarily on Energy & Materials while climate adaptation covers Life, which is further divided into Ecosystems and Species. Both are part of the increase of Resilience that is necessary for our sustained survival, and focussing on only one of the two leaves us blind to systemic shocks in the other.

It now becomes our challenge to start integrating the concept of resilience into our societal ambitions. And of course, as others have said many times already in the last few weeks, this systemic upheaval is the perfect opportunity to get our foundations straight. Adding resilience as the main KPI to all our major societal systems would be one of the best changes we could implement, for the sake of humanity (and our ability to thrive long-term). There is still a lot to develop, learn, and experiment within that department, but we already have existing tools to get us moving in the right direction.

Conclusion

Using the SiD system, several hundred projects have been executed in policy, urban development, industrial symbiosis, and supply chain optimization. While much work is left to be done to make the framework more practical for everyday use by general practitioners, it has proven to lead teams to gain new insight, and to arrive at more resilient projects.

We see that now our challenge is to start integrating the concept of resilience into our societal ambitions. To include resilience as a concept in general policy design and development, as well as in overarching evaluation frameworks such as sustainable building rating systems, or product labelling systems. As others have said many times already in the last few weeks, this systemic upheaval is the perfect opportunity to get our foundations straight. Adding resilience as a main KPI to all our major societal systems would be one of the best changes we could implement, for the sake of humanity (and our ability to thrive long-term). There is still a lot to develop, learn and experiment with in that department, but we already have existing tools to get us moving in the right direction.

SYMBIOSIS IN DEVELOPMENT

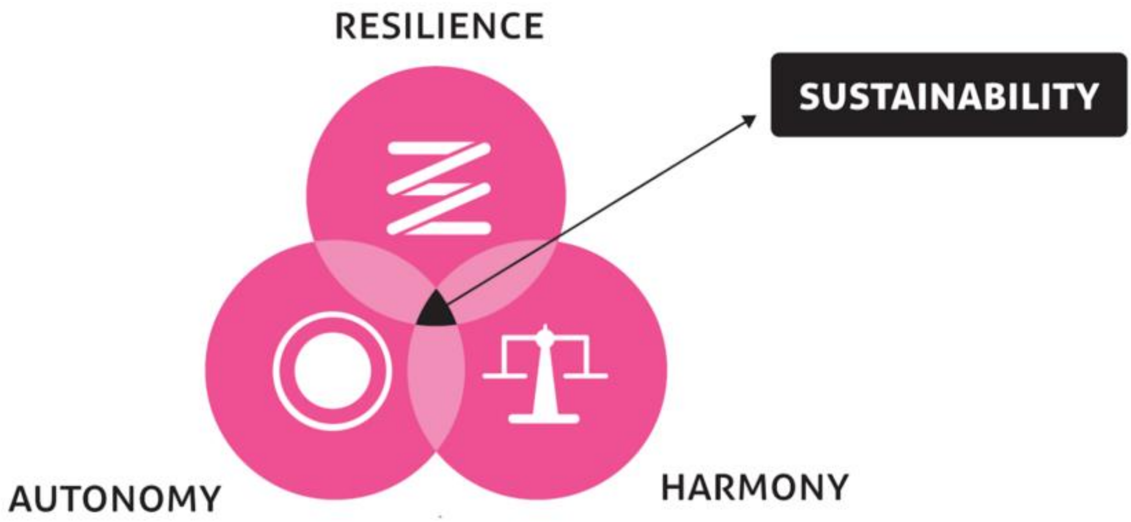

Figure 3: the system indicators of Resilience, Autonomy, and Harmony.

Applied to your specific field, the Symbiosis in Development (SiD) framework helps you understand, manage, design, and integrate resilience. The SiD framework is free, open-source, and ready for implementation in governance, design, management, and planning. It also combines and helps to integrate aspects such as the circular economy, climate adaptation, and social justice. SiD places these in relation to each other, and the overall system's resilience. While SiD extends beyond resilience, you can start by investigating its take on resilience specifically, and follow your interests from there. The main body of SiD is a free digital book to dive in deep, about 460-pages deep. There is also a quick guide that provides a birds-eye view.

There's plenty there to get you started on your own, but contact us if you are in need of guidance. All SiD materials, books, and learning materials are freely available in digital form from the thinksid.org website. If we can together integrate resilience into all of our societal systems, be it in companies, institutions, or governance, we'll be one major step closer to a truly sustainable, livable, and thriving world that can last in the reality we live in.

Acknowledgements

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Disaster City Digital Twin: A Vision of Integrating Human and Artificial Intelligence for Urban Resilience

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Summary
This study presents a vision for a Disaster City Digital Twin paradigm that can: (i) enable interdisciplinary convergence in the field of crisis informatics and information and communication technology (ICT) in disaster management; (ii) integrate artificial intelligence (AI) algorithms and approaches to improve situation assessment, decision making, and coordination among various stakeholders; and (iii) enable increased visibility into network dynamics of complex disaster management and humanitarian actions. The number of humanitarian relief actions is growing due to the increased frequency of natural and man-made crises. Various streams of research across different disciplines have focused on ICT and AI solutions for enhancing disaster management processes. However, most of the existing research is fragmented without a common vision towards a converging paradigm. Recognizing this, this paper presents the Disaster City Digital Twin as a unifying paradigm. The four main components of the proposed Digital Twin paradigm include: multi-data sensing for data collection, data integration and analytics, multi-actor game-theoretic decision making, and dynamic network analysis. For each component, the current state of the art related to AI methods and approaches are examined and gaps are identified.

Keywords
Digital twin; Machine learning; Information flow; Disaster management.

Introduction
The objective of this paper is to present a vision for a Disaster City Digital Twin as an integrated paradigm for converging different streams of research related to artificial intelligence in disasters and crisis informatics. With the increased frequency of natural and man-made disasters and crises, the need for disaster responses and humanitarian relief actions is growing rapidly (Jackson et al., 2018). The need for improving the effectiveness and efficiency of disaster management has been widely recognized, especially in the mission and policies of the United Nations (United Nations, 2019). One important area to improve disaster response and emergency management is the employment of information and communication technologies.

Disaster City Digital Twin Paradigm.
To this end, we propose the vision for Disaster City Digital Twin as a unifying paradigm for interdisciplinary convergence. In a Disaster City Digital Twin, spatiotemporal dynamics of disaster regions and humanitarian actions are integrated into an analytics platform fusing datasets from crowdsourcing tools and agencies. Through fusion, learning, and exchange of spatiotemporal information with various relief actors (enabled through data integration and visualization) and the virtual coordination, the digital twin of a disaster city can provide a vision for convergence of various streams of research related to ICT and AI in disaster response and emergency management.

Integrating the ICT and AI techniques from research conducted across different disciplines into a digital twin paradigm would require four main components in a Disaster City Digital Twin. The four components of the proposed Digital Twin paradigm are: (1) multi-data sensing for data collection, (2) data integration and analytics, (3) multi-actor game-theoretic decision making, and (4) dynamic network analysis (see Figure 1). The first component focuses on AI technologies and methods for situational data collection from multiple sources in disasters and humanitarian emergencies. Disaster situations and humanitarian crises are often characterized as data-starved due to constraint resources for data gathering and analysis. However, the advances in AI has brought opportunities to address this challenge and gather, store, and analyze various types of data related to a disaster city. In particular, AI-enabled remote sensing, social sensing and crowdsourcing technologies are discussed as important elements of the Digital Twin for near real-time gathering and analysis of disaster and crisis situations. The second component of the Digital Twin is geared towards the employment of AI in integration of heterogeneous data in order to draw important insights needed by responders and relief actors. Specifically, we discuss the challenges of dealing with different types of information (e.g., social media posts, volunteer and crowdsourced data, aerial photos, maps, reports, and news articles) and AI solutions (such as knowledge graph and network embedding) to implement machine learning on heterogeneous data to inform disaster management and relief actions. The third component of the Digital Twin includes a Serious Game Learning Environment to enable multi-actor decision making and networked coordination. In this component, we examine the employment of AI for improving disaster response training and network-centric coordination based on approaches for multi-actor gaming scenarios. The fourth component of the envisioned Digital Twin involves dynamic network analysis capturing the interactions among various types of networks such as actors and information networks (e.g., who coordinates with who; who does what relief tasks; and who needs what information) for performance assessment of disaster management and humanitarian actions. In this component of the Digital Twin, we discuss the employment of AI to examine missing links in the network and to record temporal information in order to improve the efficiency of disaster management efforts.

Through collection, analytics, training, and exchange of situational information with the humanitarian actors (enabled through data integration and visualization) and the virtual coordination (enabled by serious gaming and dynamic network analysis), the digital twin of a disaster city and its human users become smarter over time and gain predictive insights into the planning and response operations in humanitarian actions. Here, humanitarian and emergency response actors are broadly defined as robot-human teaming. The following sections present each of the four components of the Disaster City Digital Twin paradigm. For each component, we discuss clusters of recently published papers and the-state-of-the-art techniques that can be integrated into this Digital Twin paradigm and discuss the opportunities for effective employment of AI towards the realization of a vision for the Disaster City Digital Twin.

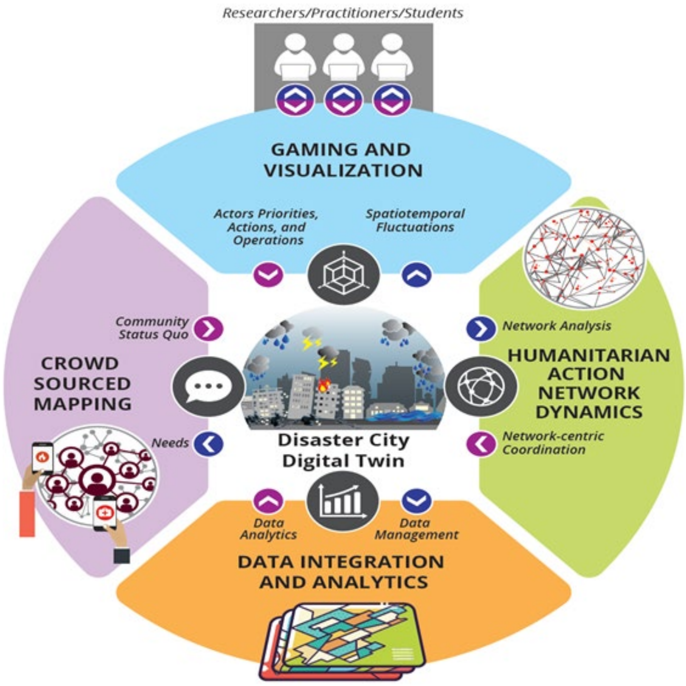

Figure 1: Overview of the Disaster City Digital Twin Paradigm

Conclusion

We provide a vision for a Digital Twin paradigm to enable interdisciplinary convergence in the field of ICT and AI for disaster response and emergency management. The proposed paradigm is composed of four components: multi-data sensing for data collection, data integration and analytics, multi-actor game-theoretic decision making, and dynamic network analysis. The convergence of interdisciplinary research streams holds a strong promise for enhancing the performance of disaster management processes. The presented vision contributes to a theoretical understanding of the convergence of various streams of disaster informatics and AI research and the advances in the interdisciplinary field. In particular, the proposed vision for digital twin contributes to establishing a common vision for interdisciplinary researchers across various fields. From a practical perspective, the proposed Disaster City Digital Twin paradigm could provide important capabilities for real-time monitoring, data analytics, and scenario simulation. First, the real-time monitoring capability of the digital twin is achieved through collection of situational data and examination of the spatiotemporal fluctuations related to disaster events such as community disruptions and damages (Chao et al., 2020). Second, the data analytics capability in the digital twin could enable better optimization of disaster management and emergency response operations among various actors. Finally, the digital twin enables the scenario-play and simulation capabilities for training and planning purposes and to improve cooperation among various and fair allocation of resources. By doing so, the digital twin of a disaster city and its human users could become smarter and more resilient to extreme events over time (Hashem et al., 2016).

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Simulation of Urban Mobility Perturbations during Crises using Adaptive Reinforcement Learning on Movement Trajectories

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Summary
This study proposes and tests an adaptive reinforcement learning model that can learn the patterns of human mobility in a normal context and simulate the mobility during perturbations caused by crises, such as flooding, wildfire, and hurricanes. The application of the proposed model is shown in the context of Houston and the flooding scenario caused by Hurricane Harvey in August 2017. The results show that the model can achieve more than 76% precision and recall. The results also show that the model could predict traffic patterns and congestion resulting from to urban flooding. The outcomes of the analysis demonstrate the capabilities of the model for analysing urban mobility during crises, which can inform the public and decision-makers about the response strategies and resilience planning to reduce the impacts of crises on urban mobility.

Keywords
Reinforcement Learning; Urban mobility; Resilience; Crisis; Simulation.

Introduction
Understanding and predicting human mobility patterns, such as destination and trajectory selection, can inform emerging congestion and road closures raised by disruptions in emergencies. Data related to human movement trajectories are scarce, especially in the context of emergencies, which places a limitation on applications of existing urban mobility models learned from empirical data. Models with the capability of learning the mobility patterns from data generated in normal situations and which can adapt to emergency situations are needed to inform emergency response and urban resilience assessments. To address this gap, this study creates and tests an adaptive reinforcement learning model that can predict the destinations of movements, estimate the trajectory for each origin and destination pair, and examine the impact of perturbations on humans' decisions related to destinations and movement trajectories.

Methodology
The proposed adaptive reinforcement learning model comprises three modules: destination prediction, trajectory prediction, and crisis scenario application (Figure 1). The proposed model uses the human movement trajectory data as input, learns mobility patterns in regular situations, then simulates the trajectories and traffic conditions in crisis situations through adjusting the reward table.

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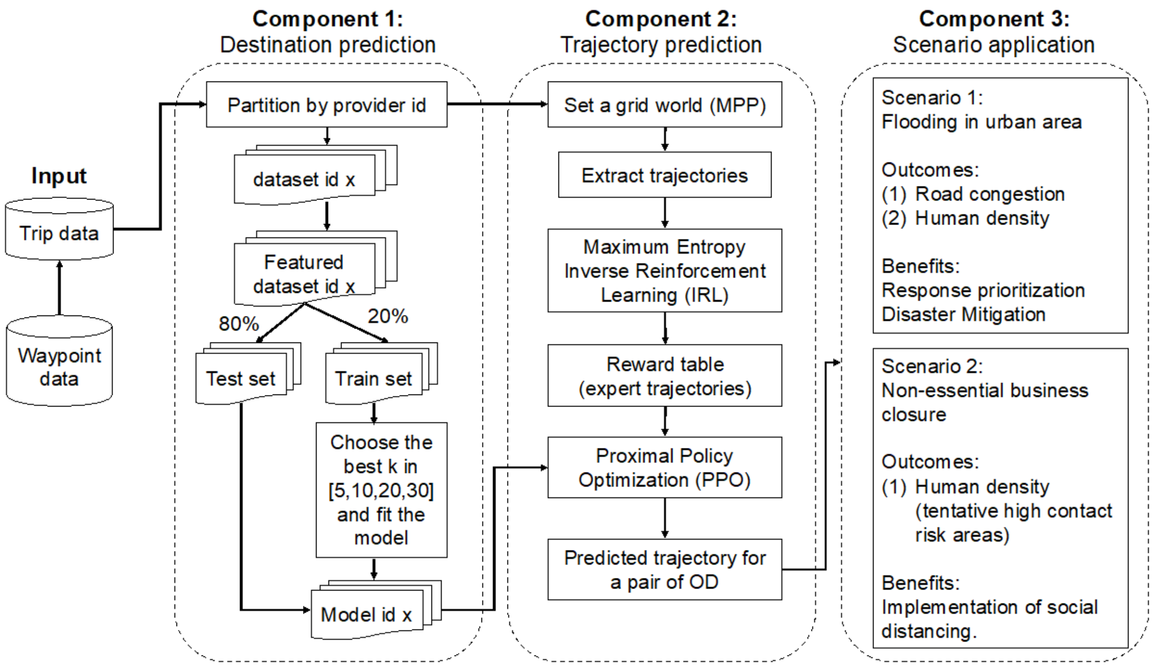

Figure 1: A schema of the proposed adaptive reinforcement learning model for simulating urban mobility.

MEASURING AND ANALYSING RESILIENCE OF INTERDEPENDENT STE SYSTEMS

TRACK C

Disentangling Resilience: Aligning Problems, Mechanisms, Paradigms and Metrics in Model-Based Decision Support

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Summary
Resilience is interpreted in various ways across different disciplines. This lack of conformity hampers our ability to quantify resilience in multidisciplinary systems. We present the Resilience Modelling Tetrahedron as a framework for making explicit the four necessary conceptual and methodological choices, and their connections, in resilience assessments involving simulation studies. These four main elements are: problem definition, description of mechanisms, modelling paradigms, and metrics for quantifying resilience. We argue that these four elements must be explicitly considered and preferably aligned and balanced, as each of them affects the others. Uncertainty can be reflected in this framework by specifying multiple alternatives for one of the main elements. The framework is meant to facilitate researchers in explicitly considering how their modelling and analysis methods fit together, both technically and in terms of answering research questions on resilience.

Keywords
Resilience, modelling, complex systems, deep uncertainty, simulation studies

Introduction
Humanity is increasingly reliant on complex socio-technical-environmental systems to provide critical services, including the provision of energy, food, and water. In the face of an increasingly uncertain and volatile future (Filatova et al. 2016; Helbing 2013; Lempert et al. 2003), understanding and improving the ability of such systems to respond adequately to shocks and disruptions—i.e. their resilience—is of critical importance.

As such systems cannot usefully be experimented upon *in situ*, *in silico* computational models have become the preferred tool for studying the behavior of such systems under a variety of conditions and assumptions (Bankes 1993; Gotts et al. 2019). However, resilience is a multi-faceted object with a variety of interpretations across different scientific and societal domains. While the underlying concept—a system's response to a (sudden) change in its environment—is straightforward, its application to simulation studies is hampered by several complicating characteristics of real-world systems, including competing interests and needs of multiple actors, system interactions across temporal, spatial, and hierarchical scales, and unclear or time-varying functional relations.

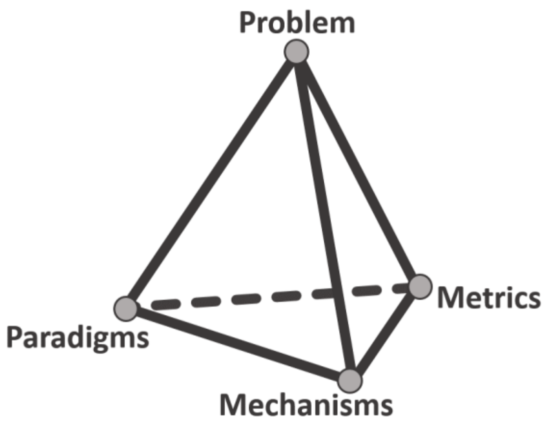

Figure 1: The Resilience Modelling Tetrahedron. The four nodes are connected by six edges, each representing an alignment to be ensured when using simulation models to study resilience.

Attempts to formalize methods for capturing this complexity in simulation models has led to a multitude of partially overlapping approaches for modelling the resilience of complex systems, using different simulation paradigms, resilience mechanisms, and metrics to study a system's response to shocks and disruptions. Modelers therefore face substantial methodological uncertainties when attempting to assess the resilience of complex systems.

We present a framework for structuring the different choices when using simulation models to study resilience. We propose a four-sided pyramid, or tetrahedron, of which the nodes represent the building blocks of resilience modelling, and the edges the alignment issues to be considered (Figure 1). Its purpose is not to provide strict rules on how to study resilience with simulation models, rather, we hope to encourage discussion on how epistemic and methodological uncertainties and choices interact when studying resilience, and how to ensure resilience studies are fit for purpose, methodologically sound, and impactful.

Four Nodes: Problem, Mechanisms, Paradigms, Metrics

We identify four main elements which must be considered in this respect. These are: the *problem* to be studied, the relevant *mechanisms* to be included, the simulation *paradigms* to be used, and the resilience *metrics* by which futures are assessed.

Resilience is not a general property of systems, but specific to actors, contexts, and temporal and spatial places (Carpenter et al. 2001; Jones 2019). It is therefore imperative to understand which question is being answered, who the problem owner is, whose resilience to which disruptions is being considered, and what the scope of the study is. We explicitly endogenize the problem into our analytical framework to highlight that no simulation study (or researcher) is objective, but always operates within the studied system.

The behavior of complex systems is governed by the interaction of their internal mechanisms and functional relations. In the context of resilience, these can include spatial and temporal distribution, heterogeneity, learning and adaptation, evolution and selection, feedbacks, buffers and redundancies. While any number of such mechanisms can be identified in a system, their relevance must be considered for the study in question.

Different modelling paradigms are available, including system dynamics/differential equation, agent-based, network, and discrete event models. These are conceptually different ways of representing the studied system. Making a choice for a specific 'modeling language' not only biases, but also restricts the insights which may be obtained (Smaldino 2019). Every paradigm has different technical, analytical, and practical attributes that bear relevance for resilience modelling and should be considered.

Simulation experiments produce an ensemble of potential futures for the modelled system. These futures can be compared using metrics. Metrics are compressions of complexity and will obscure or aggregate substantial portions of the studied system’s complexity. Thus, selection of one or more metrics must be done carefully, especially in the context of multi-actor systems with contested control (van Voorn et al. 2016) or stakeholder disagreement (Lempert et al. 2003). Many different metrics for resilience exist, and so the choice of a specific resilience metric should be made explicit too.

Six Edges: Aligning the Nodes

The edges in our tetrahedral framework represent alignment considerations, challenging the researcher to consider how their four main elements fit together both methodologically and conceptually. These alignments must be studied iteratively and bidirectionally—while a certain resilience metric might restrict the suitable modelling paradigms, a given paradigm might also constrain the implementable resilience metrics.

Matching the modelling purpose and simulation paradigm may be influenced by a number of factors including treatment of space and time, treatment of uncertainties, and data availability (Kelly et al. 2013). Similarly, certain mechanisms lend themselves to particular paradigms; e.g., complex feedback processes are best suited to system dynamics models and could not easily be captured in an agent-based model, while the reverse holds for, e.g., heterogenous social interactions. This also implies that the selection of a particular modelling paradigm may constrain the resilience mechanisms which can be implemented in it. The selection of the resilience metrics must also be aligned with the other three elements. It must give useful insights into the identified problem for all stakeholders. The metrics must also be implementable in the desired modelling paradigms, and capture the effects of the identified mechanisms.

We want to stress that while the problem is the most likely starting point for applying this framework for alignment purposes, and may therefore appear fixed, it may well be necessary to align the problem with the other three nodes at a later stage. This is particularly the case in case of methodological, fiscal or temporal constraints on the analysis—the need to use a particular method to fulfill funding requirements, a lack of budget for costly simulation experiments, or an imminent deadline precluding certain approaches. No node or edge of the tetrahedron is more important than the others—its alignment should be isotropic.

Deep Uncertainty in the Tetrahedron

When using simulation models to study the resilience of complex systems, modelers face several choices in how to represent and analyze the system. While there is no right or wrong way of doing this, these choices will both bias the conclusions, and also restrict the questions that can be answered. It is therefore critical to ensure that these choices are thoroughly aligned with one another, and critically reviewed.

We expect that it may often not be possible to specify a single set of resilience mechanisms, modelling paradigm, or resilience metric. This may be because the functional relations in the system are unclear or disputed, stakeholders cannot agree on the metrics by which to evaluate futures, or there is no natural alignment between two or more of the resilience modelling elements. In such cases, we believe that analytical methods from deep uncertainty (Lempert et al. 2003) may be useful. For example, it may be desirable to, e.g., create multiple versions of a model, each capturing different (combinations of) resilience mechanisms, if the exact mechanisms at play in the real system are uncertain. Similarly, it may be necessary to implement these models in multiple paradigms, or at multiple levels of granularity, to reduce bias and potentially discover unexpected behavior. Finally, multiple metrics might be used to account for irreconcilable stakeholder interests, or to discourage strategic behavior or "gaming" (Manheim 2018). Established analytical methods such as sensitivity analysis (Saltelli et al. 2019; ten Broeke et al. 2016) or scenario discovery (Bryant & Lempert 2010; Steinmann et al. 2020) can then be used to understand the implications and differences between these alternatives. We note that the basic tetrahedron has six alignment edges, but adding one alternative each at two nodes (e.g., implementing the model as both an agent-based and a system dynamics model, and considering two possible resilience metrics) more than doubles this number. This may substantially increase the effort required to align all the elements.

Conclusion

When using simulation models to study the resilience of complex systems, modelers face several choices in how to represent and analyze the system. While there is no right or wrong way of doing this, these choices will both bias the outcome of the analysis, and restrict the questions which can be answered. It is therefore critical to ensure that these choices are both aligned with one another, and critically reviewed. We present a framework, the Resilience Modelling Tetrahedron, which may be useful in this process. By representing the four main choices in resilience modelling as the nodes of the tetrahedron, the necessity of aligning them is made explicit. The framework to be presented hopefully creates awareness among modelers who work on resilience and may increase the impact and soundness of their work.

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Resilience Modeling and Analysis of Telecommunication Networks

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Summary
Telecommunication networks play an important role in the functioning of society today, therefore their resilience is critical. To determine the resilience of these networks, a nine-step resilience management process was utilized. Within this process, the network is modeled which can provide insights into how telecom networks operate and the best ways to improve their resilience. Using a simulation framework developed at Fraunhofer EMI, telecommunication networks are modeled against a variety of adverse events, including both physical and cyber-attacks.

Keywords
resilience modeling; telecommunication; critical infrastructure; resilience quantification; network simulation

Introduction

Critical infrastructures (CI), and their resilience against natural disasters or attacks, can have a large influence on the functionality of society. Failure of these infrastructures halt society's communication, transportation, commerce and more. This research applies a resilience management method to different types of telecommunication networks where the networks are modelled and simulations against a variety of threats are completed. This is all done in the EU H2020 project RESISTO (RESISTO 2020).

The resilience management process used in RESISTO, as defined in (Häring et al. 2017), is a nine step process adapted from the ISO 31000 risk management process (International Standard ISO 31000:2018). It extends the risk management process, with nine steps in total: 1. Context analysis, 2. System analysis, 3. Identification of System performance functions 4. Identification of disruptions, 5. Pre-assessment of system functions and disruptions' critical combinations, 6. Quantification of the overall resilience, 7. Evaluation of the resilience, 8. Resilience improvement measures selection, and 9. Design and implementing of resilience improvement measures (Häring et al. 2017).

This contribution will focus on the simulation steps, namely steps 6 through 9 in the resilience management process.

Use Case

The use cases to be tested are divided into three different groups: current technologies, used as a baseline, interconnected critical infrastructures and future technologies, mainly 5G. Each of these groups contains a number of use cases that investigate different aspects. This contribution will focus on the current technologies group.

The scenarios in the current technologies focus on communication networks including phone, data and television. Adverse events tested in this group include Distributed Denial of Service (DDoS) attacks, malware, bombs and natural disasters.

Simulation Framework for Resilience Analysis

The simulation tool used in this study models networks in a topological and flow based manner and in general works by simulating damages on a network model, propagating that impact over the network and evaluating the impact of those damages with user defined performance measures (Hiermaier et al. 2017). The recovery of damaged nodes is also included in the simulation. The output of the simulation tool is a performance time curve that can be analyzed to determine the resilience of the network against a specific threat. Mitigation measures focused on the critical components can be added to the network model and the simulation will determine the effects those measures have on the resilience performance, i.e. by producing a new performance time curve for comparison.

The testbed network was designed by creating an edge and node list from the test bed diagram as provided by project partners. The arcs between nodes are considered directed, therefore the direction of flow between the nodes needs to be accounted for. Each node has a list of attributes, which are used as a way to introduce more characteristics into the model. Currently, attributes include the mean time to repair, and the capacity. However, further attributes may be added including the type of network the node contributed to (TV, data, or voice), the detection time of a threat on the node, if the node is virtual or not, and a list-of-strings section that can include other important information such as dependencies (if the node needs a power source, or if the node is located in a specific building).

When the threats (DDoS attacks, natural disasters, etc.) are implemented in the simulation tool, additional information is also included. General information for each threat includes the start time and end time, the area of attack and which components of the network are affected (nodes, arcs or both). The threat can attack in various manners including attacking a specific node, number of nodes or nodes in a region defined by radius from origin of the threat. The simulations are run repeated times to build a representative sample of simulation outcomes. The performance is evaluated, and critical nodes are identified. With this information and the understanding of the network, suitable mitigation strategies can be developed ranging from introduction of redundancies in the network to what-if scenarios generation and documentation of suitable steps for better preparedness. In case of network modifications, the modified network can be subjected to the same simulation process and this can be repeated until results of interest are obtained.

Conclusion

The work addresses understanding of operation of telecommunication network with respect to modeling of the network for resilience quantification, improvement and management. The work further tries to address modeling of physical and cyber threats with respect to this network. This work is motivated from the resilience framework as introduced in (Häring et al. 2017) that covers resilience management in a nine-step cycle. The simulation framework, CaESAR, is introduced as a tool that can implement the modeled network using a probabilistic model for threat simulation and damage propagation which addresses the steps six through nine of the resilience management cycle. The modeling approach and performance evaluation has been demonstrated with a test bed. In the end it is shown how this modeling approach can identify the critical components in the network by demonstrating the impact of an attack on these components. Furthermore, impact of suitable mitigation strategy on the performance has been illustrated to complete the steps of the cycle. This work concludes that an effective/comprehensive study of the CI networks using the resilience cycle as introduced in (Häring et al. 2017) with the modeling approach described can help telecommunication operators to better manage and improve the resilience of their infrastructures which is in the best interest of any society. With suitable understanding this modeling approach can be extended to other CIs and also be used to identify deep critical dependencies and deadlocks within dependent CIs which also is the future scope of this work.

Acknowledgements

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Development, Validation and Assessment of a Resilient Pumping System

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Summary
The development of resilient technical systems is a challenging task, as the system should adapt automatically to unknown disturbances and component failures. To evaluate different approaches for deriving resilient technical system designs, we developed a modular test rig that is based on a pumping system. On the basis of this example system, we present metrics to quantify resilience and an algorithmic approach to improve resilience. This approach enables the pumping system to automatically react on unknown disturbances and to reduce the impact of component failures. In this case, the system is able to automatically adapt its topology by activating additional valves. This enables the system to still reach a minimum performance, even in case of failures. Furthermore, time-dependent disturbances are evaluated continuously, deviations from the original state are automatically detected and anticipated in the future. This allows to reduce the impact of future disturbances and leads to a more resilient system behaviour.

Keywords
water supply system, fault detection, anticipation strategy

Introduction
At the collaborative research centre CRC 805 we conduct research on transferring the resilience concept to the domain of mechanical engineering. We evaluated multiple metrics to quantify the resilience of technical systems, as shown in (Altherr, et al., 2018) and developed optimization based strategies to derive more resilient system designs, cf. (Altherr, Leise, Pfetsch, & Schmitt, 2019). We propose the following understanding of a resilient technical system in mechanical engineering: “A resilient technical system guarantees a predetermined minimum of functional performance even in the event of disturbances and failures of system components, and a subsequent possibility of recovering”, cf. (Altherr, et al., 2018, p. 189). A resilient technical system has to be “safe to fail” (Ahern, 2011) and should have the possibility to recover, as for instance shown by (Bongard, Zykov, & Lipson, 2006) for a star-shaped robotic system. To achieve this desired behaviour, we present research results conducted in this area to evaluate this concept practically based on an example system.

Test rig
With our test rig, cf. Fig. 1, we can quantify and continuously assess the resilience of different system designs, i.e. pumping systems that have different system topologies and are equipped with different control algorithms. The functional performance of each system is given by the water height in each one of the two acrylic cylinders on the right side in Fig. 1. We implemented a digital control and measurements system that is based on National Instruments hardware and the Python programming language. All sensors and actuators can be read and controlled digitally and we can use up to three pumps and up to ten control valves. The valves can either be used to simulate external unknown disturbances and/or to derive topology adaptions. We measure the water pressure, temperature and pump power in real-time on the affiliated computer system which allows for the implementation of common control strategies as well as new resilience-improving control strategies.

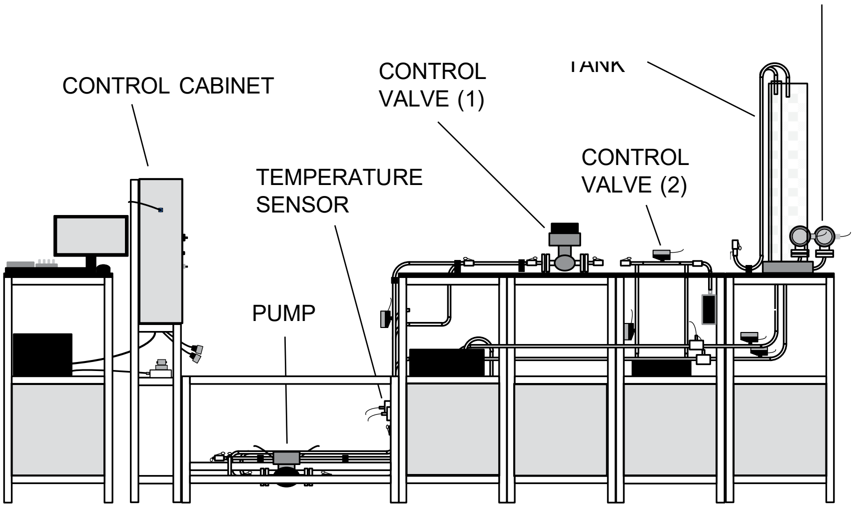

Figure 1: Test rig for resilient system design evaluation

Assessment of Resilience

We distinguish between two different failure types, comparable to shocks and stresses. First, (static) failures, which are given, if specific components within the system fail and the mean time to repair is long in comparison to the system time for fulfilling its function. This is comparable with the failure scenario given in (Bongard, Zykov, & Lipson, 2006), where a leg was removed from a resilient, star-shaped robot, which learned to cope with this failure. In our case static failures are simulated by deactivating actuators as for instance one pump or valve.

Second, (dynamic) disturbances, which lead to a temporal loss in functional performance in the same time-scale as the system time. We can simulate this behaviour by using a control valve (marked with (1) in Fig. 1) to disrupt the system at a given point in time, after the steady-state is reached.

For achieving a resilient system design, we transfer the four key abilities/functions (*monitoring*, *responding*, *learning*, and *anticipating*) identified by Hollnagel, cf. (Hollnagel, 2012), (Hollnagel, Prologue: the scope of resilience engineering, 2011), and (Hollnagel, RAG - The resilience analysis grid, 2011), for general systems to the engineering domain.

The first two (*monitoring*, *responding*) are usually already implemented in technical systems which are often equipped with controllers. The further two functions *learning* and *anticipating* are however not commonly implemented.

For assessing the resilience of the pump system, we use among others an adaptation of the resilience triangle, as shown by Bruneau et al. (Bruneau, et al., 2003) to quantify dynamic disturbances.

Furthermore, we present a simulation model of the test rig that is used in a Monte Carlo simulation. With this approach, we are able to simulate specific system failures and compare the benefits of multiple controller types to evaluate the performance in case of unknown failures. Since monitoring and responding are commonly implemented in technical systems, we focus in the following on the additional functions learning and anticipating.

Learning

For the learning step, we present different approaches. We present a rule-based approach in which the system controller evaluates the performance measure in real time and detects dynamic disturbances rapidly. With this approach we are able to detect the beginning and end of dynamic disturbances as for instance a periodic disturbance of an arbitrary shape. We use a decay function to reduce the set point value of the control variables after a disturbance ends. This allows to meet the system performance of a classic reference system without disturbances in the long run but improves the short-time resilience behaviour significantly.

Furthermore, we equip the system with a forecasting model for its performance loss due to future disturbances based on time-series forecasting methods, cf. (Brockwell & Davis, 2016) and (Isermann & Münchhof, 2010). We use an iterative learning process to continuously adapt this forecasting model, which improves based on each disturbance the system experiences. This allows for better and better performance in anticipation of disturbances which is treated in the next section.

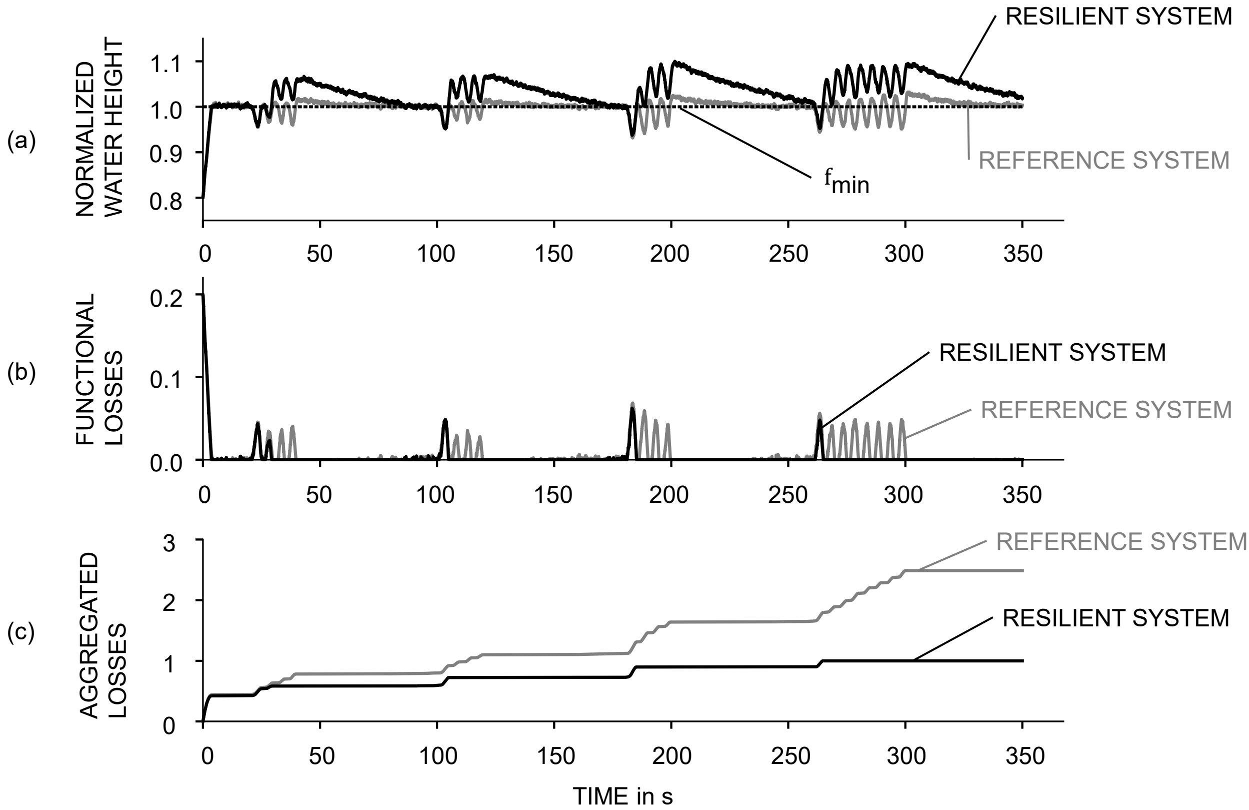

Figure 2: Simulation of the test rig main functionality with external disturbance by control valve (1) in Fig. 1. Subfigure (a) shows the defined minimum performance $f_{\min}$, the normalized system behaviour for the classic reference system design, and the resilient design, which improves its behaviour in the second disturbance, based on the previous experienced one. (b) shows the normalized performance loss over time. (c) shows the aggregated performance loss over time for both systems. It is normalized with the loss of the more resilient system.

Anticipating

The disturbance model which we derived in the learning step is used in an anticipation step to reduce the future impact of unknown disturbances. We present a rule-based approach that uses the disturbance forecast to avoid losses in future disturbances. This is shown in Fig [2] (a). The resilient system is capable to detect and predict the arbitrary periodic failures and to change its behaviour to avoid the anticipated losses.

Once the disturbance ends, the system is able to return to its original behaviour. If a new disturbance occurs this system changes its behaviour again and adapts to the new disturbance to minimize future losses based on the adapted disturbance model.

The comparison between the losses of the reference classic system which uses only a monitoring and responding functionality and the more resilient system that uses all four functions of a resilient system is shown in Fig [2] (b) and in an aggregated form in Fig [2] (c). The resilient system with all four abilities is able to detect disturbances rapidly and avoids disturbances in the near future by adapting its behaviour. This reduces the aggregated losses significantly over time.

Conclusion

We presented a modular test rig that allows us to assess different system design approaches and resilience metrics. Furthermore, we presented a simulation approach for the given system and showed the influence of different learning and anticipation strategies. All shown steps (resilience quantification, system model design and the development of an anticipation strategy) lead to a more resilient system design. Using an iterative learning approach, disturbances can be estimated and the system can adapt accordingly to maximize its functional performance.

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Towards a Common Ontology for Investigating Resilience of Interdependent Urban Systems

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Summary
In the presented work, we aim to investigate the overall resilience of the interdependent critical infrastructures (CI) energy, water and information and communication technology (ICT). Due to its multidisciplinary character, a joint resilience evaluation of interdependent CI networks such as water and electricity is a challenging task. The presented work proposes to approach this challenge by developing a common ontology within which the interoperability between the heterogenous domains (CI networks, resilience evaluation, disruption events) is ensured by the means of an upper-ontological level. Moreover, a novel methodology of classifying disruption events is proposed, distinguishing disruption events based on their temporal and spatial scope. This abstract and generalised classification will allow us to assess the resilience regardless of the specific cause of an event. It is argued that a common ontology will improve resilience evaluation by preventing organisational errors, information redundancies and inconsistencies.

Keywords
Resilience; Critical Infrastructure; Ontology; Water-Energy-Nexus; Interdependence

Introduction
Current trends in urban development point towards the establishment of Smart Cities. This term reflects increasing permeation of the urban sphere with information and communication technology (ICT) [1, 2]. While the digitalised control of the already inter-linked urban water and energy supply networks with the communication networks is beneficial in numerous ways, it also increases the interdependence between the critical infrastructures (CI) which gives rise to new vulnerabilities.

Problem Statement
The presented work is part of the LOEWE-Project emergenCITY, in which we aim to study jointly rather than separately the resilience of various urban CI networks such as energy, water and ICT. This will allow for an improved overall evaluation, since interdependence of different types of CI can be responsible for increased vulnerability as a disruption affecting one network may ripple across to others in case of strong coupling [3]. Modelling, development, operation and maintenance of the different networks rest in the hands of different strands of the engineering domains while representatives of other disciplines such as sociology, history and law consider the behaviour of their users. These groups need to collaborate to study the effect of disruptions on infrastructure of digital cities and their communities [4]. Due to the strong heterogeneity of these groups, it is essential to agree on a common language with regard to disruption events when developing a strategy to improve the resilience of urban CI.
Consequently, we propose to develop a common ontology for the water and energy networks within which these events can be expressed and which makes it possible to interpret those events with regard to their effect on the interdependent networks. This will allow us to assess their combined resilience.

Terminology
In the following section, the understanding of the terms CI, resilience and ontology is clarified, as these are the most central to our work.
The European Union defines CI in legislation as: “An asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people.” [5] By contrast, the definition of the United States stresses the aspect of collaboration between individual infrastructures which is a precondition for the successful delivery of essential goods and services, since none of the CI networks individually fulfil all of the functions referred to in the EU definition, and none of the functions are fulfilled in total by one specific CI [6].

The concept of resilience has been defined in various ways by different organisations and authors [7–9]. A meaningful interpretation of this concept for the domain of engineering which considers the interpretations of resilience in various other disciplines is given by Altherr et al.: "A resilient technical system guarantees a predetermined minimum of functional performance even in the event of disturbances or failure of system components, and a subsequent possibility of recovering at least the setpoint function." [10] They further identify four resilience core functions, namely monitoring, responding, learning and anticipating.

Finally, it is necessary to clarify what is understood by the term ontology in the context of this work. Originating in philosophy, ontology is also used in computer engineering where Gruber defines it as "an explicit specification of a conceptualization." [11] The following interpretation of this definition is given by H. Sack: conceptualization denotes the abstract model of the most relevant concepts and relations in a domain of interest. It is explicit in that the meaning of each of the components must be defined. The multiple stakeholders in the ontology must have the same understanding of the concepts and their definitions. Furthermore, for beneficial use in computer engineering it should be formalised so as to be machine understandable. [12]

Relevant Work

Several ontologies have been proposed in the context of emergency response [13–17]. Kontopoulos et al. developed an ontology for climate crisis management [18]. Further works also consider CI interdependencies [19–21]. Specializing on federated simulation frameworks for investigating the dependencies between critical infrastructures, Tofani et al. developed a knowledge base system based on ontological formalism [22]. However, most of these works are concerned with ontologies intended for emergency or crisis management and situation assessment, not resilience analysis. As such, they mainly serve to describe the situation and assist humans in the decision process rather than to perform engineering analyses and evaluate resilience metrics. While they often manage to include social aspects, an in-depth ontology capable of capturing the cyber-physical nature of infrastructures with a simultaneous possibility of resilience assessment has not been proposed so far.

Developing an Ontology

In order to design an ontology capable of providing a stable basis for resilience analysis of interdependent CI systems, the fundamental methodology of Uschold and Gruninger [23] and the methodology for catastrophe situation assessment of Little and Rogova [15] are used. According to Uschold and Gruninger, developing a formal ontology should start by identifying the motivating scenarios. In the present case, the motivation lies in the need to assure interoperability between three key aspects: the interdependent CI networks, the disruption events and the resilience metrics. Following [23], we specify a set of competency questions (natural language sentences the ontology should be able to answer), such as "What is the minimum required water/energy supply of a specific city district?" and "Which components of the CI are still functioning during a disruptive event?".

The description of disruptive events and their effect on CI is not a trivial task. We define disruptive events in that we identify potential causes of disruptions. Abstracting from specific causes, we categorise disruptive events along generalised criteria common to all realistic disruptive events. These are the temporal and spatial scope of a disruptive event (instantaneous/persistent, local/global), as shown in Figure 1. E.g., an event that causes a disruption of just one component in the water network but several components distributed throughout the studied domain in the energy network is classified as global, since the scope in both networks is observed in analysing the disruption event. Similarly, components failing in both networks at the same geographic location are interpreted as a local disruptive event. The temporal scope of the disruptive event is determined by the time frame within which the first and the last disruption occurs. Rather than planning the robustness of the CI against a set of specific pre-defined events, this simple yet comprehensive classification will allow us to assess the resilience of the CI faced with any given disruptive event.

This categorisation is a first step towards deriving an ontology for the domain of disruptive events. Further ontology domains will be developed for the CI networks and the resilience metrics based on the existing ontologies, lexical sources, scientific literature and domain experts. While the domain-specific ontologies provide concrete content necessary to understand a situation, an upper-level ontology can improve the analysis of numerous domain-specific items by informing about the domain's metaphysical structure [15]. As a result, we identify the need for an upper-level ontology (ULO) which is able to integrate the domain-specific ontologies of individual CI networks, resilience evaluation and disruption events. We propose to find a suitable ULO upon consideration of the existing models (e.g., [20, 22]). The main challenge will lie in expressing interdependencies and linking the events with the CI networks.

Measuring and analysing resilience of interdependent STE systems
Quantifying, measuring and monitoring resilience of systems

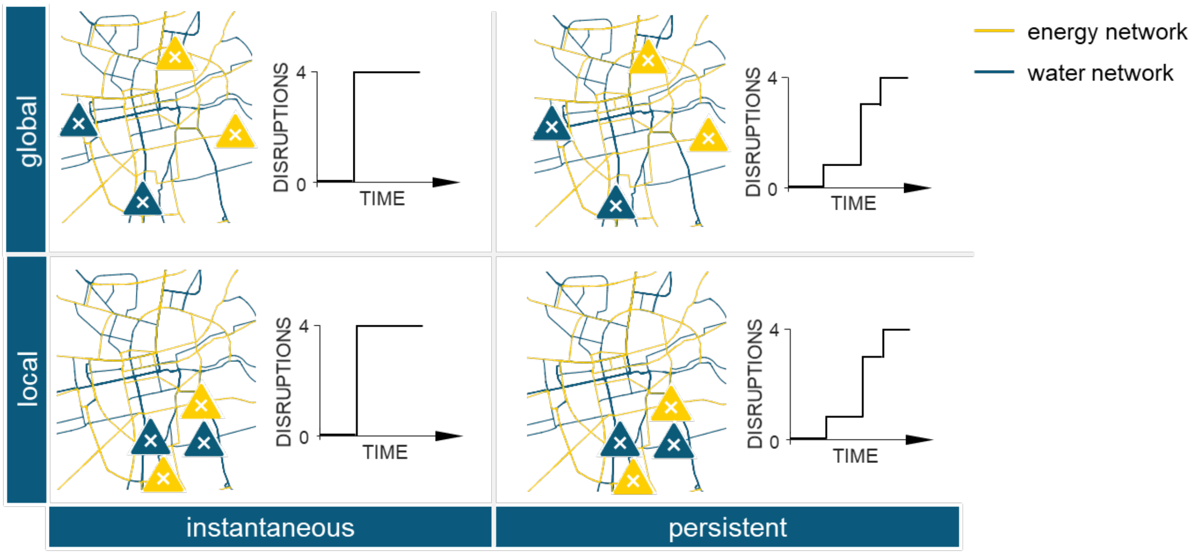

Figure 1: Classification of disruption events.

Conclusion

We identify a common ontology as an appropriate approach to assess the combined resilience of interdependent CI. Aside from describing CI networks, the ontology will be designed to account for the effect of various disruption events on a generalised level. The basic categorisation proposed here can easily be expanded to include concepts as intensity and temporal evolution of a disruption as well as a continuous scope rather than discreet categories, in case this proves more advantageous. In future work, we will show that a common ontology can in addition improve the overall resilience of interdependent CI by avoiding information redundancies and enabling a coordinated response from all networks.

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Experimental assessment of the robustness of a wireless sensor network used for early warning of flash floods

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Summary
We present a wireless sensor network for monitoring the hydro-meteorological state of a catchment of approx. 35 km^2, known as Quebrada de Ramón, at the foothills of the western Andes, that drains directly into the city of Santiago de Chile. The city is exposed to occasional flash floods from this catchment, which can have a strong impact on the population and built environment. In this work we provide a formal definition for quantifying the *robustness* of sensor networks used in early warning applications, and quantify the robustness of the Quebrada de Ramón network empirically.

Keywords
Wireless sensor networks; early warning systems; robustness.

Description of the study site

The Southern Andes in the central part of Chile are characterized by a complex terrain [1]. Rain events that are generated there are often due to warm winter storms along with the presence of cold fronts and the influence of the southeast Pacific anticyclone [2]. The main cause of flash floods due to rainfall in this region are abnormally-warm rain events, with the isotherm of 0 ◦C located at high elevations [3]–[5]. The capital of Chile, Santiago, located at the foothills of the Andes, is therefore exposed to flash floods and landslides, which can have severe socio-economic and environmental impacts on the city. More than 15 floods and debris flows have occurred since 1980, affecting thousands of people and causing more than 80 fatalities and economical losses of more than 17.5 million USD [6]. As an example, the event of May 1993 occurred under abnormal conditions of the 0 ◦C isotherm, whose elevation rose from the typical altitude of 2000 m above sea level (masl) to approximately 4000 masl [7]. One of the ravines in which the floods originated was Quebrada de Ramón (QR).

The lower parts of QR at the city's edge have cellular coverage, but otherwise there is no energy nor communications infrastructure anywhere in QR. For this reason, wireless sensor networks (WSN) are a natural candidate technology for monitoring for flood conditions in mountain catchments such as QR.

Wireless sensor network for hydro-meteorological monitoring

A WSN is a set of sensing devices that communicate wirelessly with each other in coordinated fashion in order to fulfill a specific task, such as monitoring meteorological and hydrological variables within the

QR catchment [8] and uploading them to an inference engine in the Cloud where the data is processed and the risk of floods is evaluated.

The proponents have been doing research, development and field tests of WSN technologies since 2011. As an essential component of a prototype early warning system of flash floods, they deployed and have been operating a WSN in the QR catchment since 2014. The network, fully developed in-house, is composed of 17 stations, located at elevations between 878 and 2962 masl (Figure 1). The sensor nodes measure several hydro-meteorological variables every 10 minutes, along with diagnostic information about the nodes' operational status. The measurements are relayed over the network in multiple hops using the Sensorscope communication protocol stack [8]–[10] to a sink node with cellular communications access that uploads the data to the Sensor Network Administration Platform (SNAP) in the Cloud. SNAP is a software platform developed in-house for managing user access by site, variable and time range, as well as for adequately processing and storing each data point in a database for later access. SNAP provides an API (application programming interface) for accessing the data by means of computer programs for performing data analytics. Hydrological and meteorological models access the SNAP data (among other sources) this way in order to forecast flooding events.

Fig. 1. Map of the Quebrada de Ramón wireless sensor network for early warning of flash floods.

Resilience and robustness of a sensor network

A critical operational aspect of WSNs used for early warning of flash floods is, evidently, that it has to be able to provide data continuously and reliably to the Cloud within given upper bounds of data loss and data delivery time under largely varying weather conditions. This raises a question of resilience: How resilient is this sensor network for fulfilling its monitoring task reliably? It must perform this duty with minimal human intervention, specially so during extreme precipitation events, when the adverse conditions put the network under highest operational stress and access to the sites for repair would be too risky.

In this work, we take a first step towards answering the above question by proposing an approach for determining the robustness of a sensor network.

The concept of robustness has been widely addressed in the literature. The general consensus among various disciplines is to understand robustness as the ability of a system to tolerate stress or changing conditions without degradation of its performance or system downtime [11]–[17]. In contrast, Sterbenz et al.'s [18] define resilience as the ability of the network to provide and maintain an acceptable level of service when subject to faults and disturbances that challenge normal operation. The difference between robustness and resilience is thus indeed murky, although Laprie provides a clue to their central difference by associating resilience with justifiable reliability in face of changes [19]. Hence, we understand robustness as an attribute of system performance, a success rate of meeting or surpassing a predefined performance threshold, while resilience is an understood quality of the underlying mechanics designed into a system, based upon which robust performance and other virtues rest. Robustness does not provide clues about why or how the performance is met or not. Resilience does. Consider thus the following meaning of robustness for a WSN: Given a required communication performance for an intended application, the network is more robust the higher its success rate in achieving or surpassing that performance requirement. For application in early warning of flash floods, we propose to define the communications performance by two metrics:

1. The time it takes for the measurements acquired in the field to reach the inference engine in the Cloud (Sensor to Cloud Delay, S2CD) is required to be below a given deadline or else the measurements are not useful anymore for early warning use.
   In the case of QR the deadline is 30 minutes. It is to be noted that in order to conserve energy, the sensor nodes sleep most of the time, hence the measurements take time to hop from sensor node to sensor node and reach the Cloud server.

2. The fraction of measurements that reach the inference engine within the deadline (Measurement Delivery Ratio, MDR) is required to be above a given proportion in order for the engine to be able to make reliable predictions.

For the QR inference engine, the minimum required MDR was defined to be 70%.

Because not all measurements reach the Cloud with the same S2CD, statistics can be made about how the MDR grows with longer S2CD (S2CD can be determined by the difference between a measurement's acquisition and cloud arrival times). This provides a quantitative method for determining if a network meets the robustness criterion or not, by looking if the value of MDR achieves the minimum requirement (70%) at an S2CD equal to the deadline (30 minutes). In the sequel we report on empirical results obtained about this from the QR network.

Results

MDR cumulative statistics vs. S2CD of the QR network are presented in Figure 2. It is to be noted that the network attains the condition for robustness (yellow bar at S2CD= 30 min is taller than 70 %). We also observe that 98 % of the measurements eventually reach SNAP in the Cloud (blue bar at left).

The sensor nodes are equipped with an on-board non-volatile memory card that allows for recording network topology information such as present neighbors at a given time and their hop-count to the sink node and so on. For bandwidth restrictions, this data is recorded locally and not relayed over the network itself. Snapshots recorded this way every 5 min were retrieved manually and merged offline with environmental measurement series downloaded from SNAP. This allows for disaggregating the statistics of Figure 2 by hop count and obtain Figure 3. Clearly, measurements relayed over longer paths across the network (larger hop-count) take longer to reach the Cloud. Measurements from nodes at 2 or more hops from the sink do not fulfill the robustness condition. This is a key insight, because nodes in the QR network with higher hop-count are also located further up-streams into the catchment. Getting their data in timely fashion is crucial for the early warning attribute of the system.

Finally, by looking at the S2CD statistics presented in Figure 4, we find that for all hop-counts there are measurements that reach the Cloud within the deadline of 30 min. However, each additional hop adds on average 7.4 min to the S2CD and increases the S2CD variance significantly.

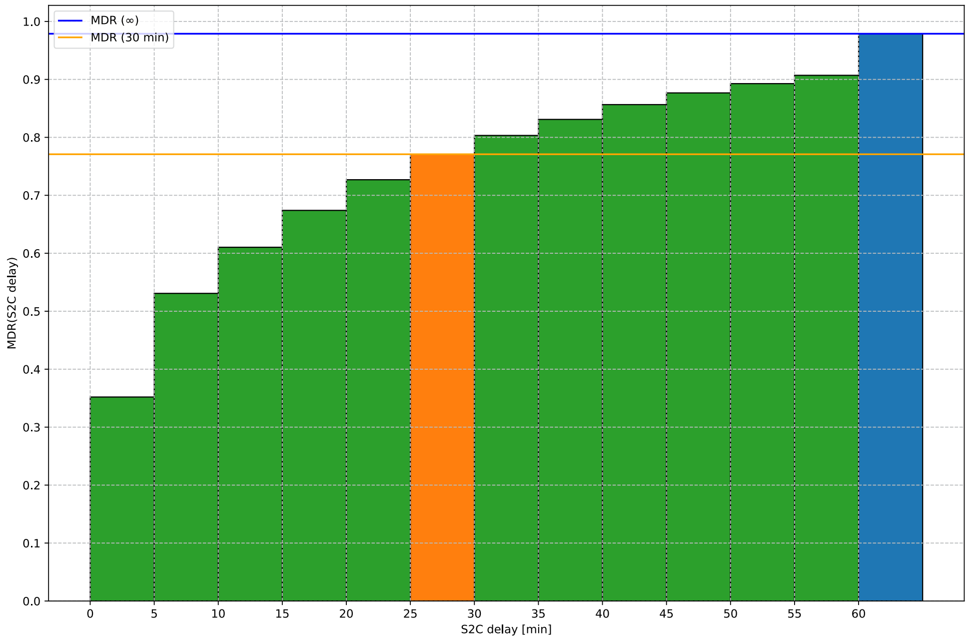

Fig. 2. Statistics of Measurement Delivery Ratio (MDR) as a function of Sensor to Cloud Delay (S2CD) from the Quebrada de Ramón wireless sensor network.

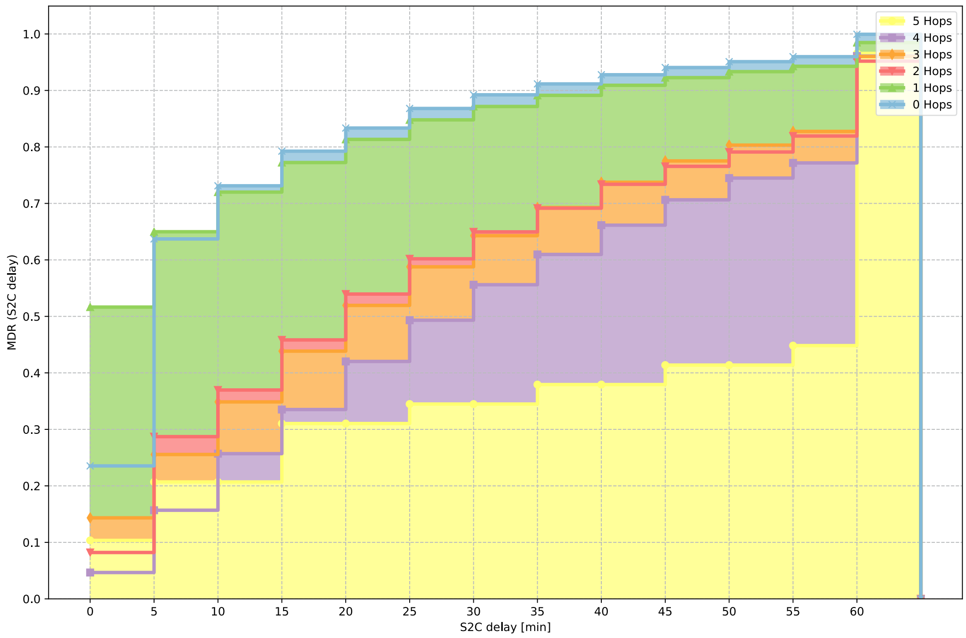

Fig. 3. Statistics of MDR vs. S2CD disaggregated by number of hops.

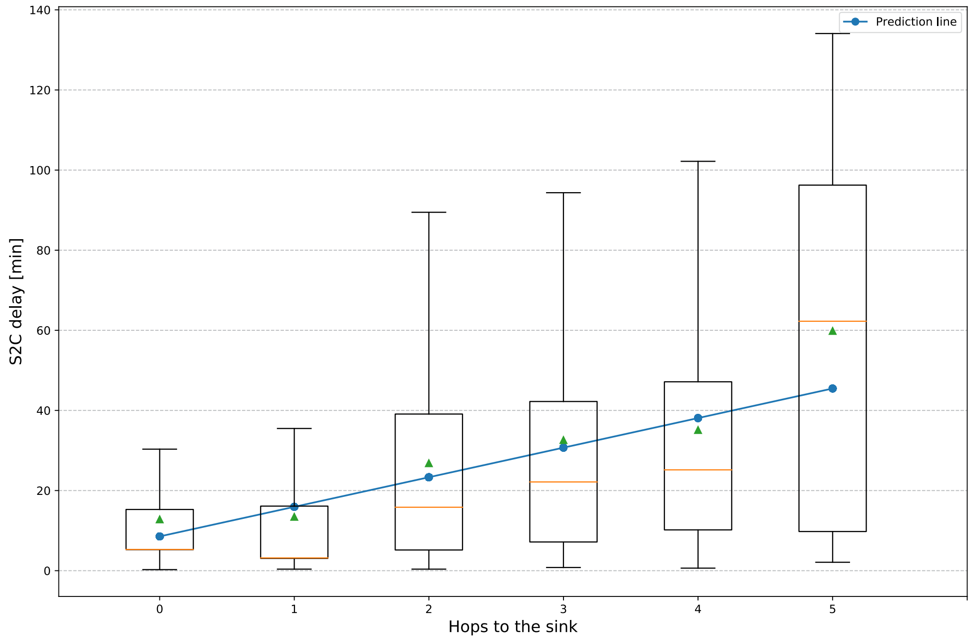

Fig. 4. Boxplot of S2CD by hop-count (green triangles: mean value; orange lines: median; linear regression intercept is 8.552 and slope is 7.385).

Conclusions

We have presented an empirical evaluation of the robustness of a wireless sensor network used for early warning of flash floods. Even though the network meets the robustness criterion on average, the methodology also reveals that measurements from nodes located at larger hop-counts from the sink do not. This is a critical aspect that must be addressed in future work.

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Modelling real-life value networks with supply disruptions and demand uncertainty

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Summary
Real-life value networks, a.k.a. supply chains, consist of a multitude of independently operating nodes, i.e. manufacturing companies, each managing their incoming materials, intermediates, and outgoing products. Each of these nodes may face disruptions of their manufacturing activities due to internal and external events, such as machine breakdowns, product quality issues, floods, and earthquakes. We want to understand the impact of these local disruptions on the network performance. We build on the well-developed theory of multi-echelon inventory systems and extend these models with supply disruptions. As this extension yields mathematical intractability, we develop a heuristic and test its accuracy using discrete event simulation. We conclude that the accuracy is sufficient for practical purposes. We find that the average inventories under an optimal policy are insensitive to the disruption rate. The richness of the model allows to identify effective risk mitigation strategies.

Keywords
supply disruption; demand uncertainty; multi-item multi-echelon system; base stock policies; insensitivity

Introduction

The COVID-19 pandemic has revived the interest in resilient supply chains. Strategies for resilience have been described in Sheffi (2007). Yet such strategies are primarily design oriented, taking into account geographic risks and supplier and market dependency. When disruptions are high impact and take a long period of time, it is economically inviable to prevent supply chains to halt, as this would require holding strategic stocks for long periods of time, until a major disruption occurs. Consequently, disruptions like the pandemic simply halt the supply chain, and efforts are concentrated on recovery from the disruption. In the context of supply chain management, recovery from major disruptions requires transparency on the availability of components and sub-assemblies across the supply chain, a sales plan that represents the (global) market situation in the situation at hand, and a planning logic that is capable of generating a material-constrained order release plan for all production units in the supply chain. We refer to De Kok et al. (2005) for such a logic, which has been used successfully in the high-volume electronics supply chain during periods of high demand volatility.

In this paper we aim to provide insight on the impact of medium- to high-frequency disruptions with low to medium impact. We build on the earlier work of Henig and Gerchak (1990), Bollapragada and Morton (1999), Bollapragada et al. (2004), Atan and Snyder (2012). Our major contribution to this work is the extension from single-item single-echelon models, and serial multi-echelon models, to multi-item multi-echelon models that represent real-life supply chains. Such supply chains are in fact nothing like chains, but merely networks where an item may have multiple child items and multiple parent items. The quantitative model proposed assumes periodic review echelon base stock policies, i.e. every time an item is ordered, it aims to increase its echelon inventory position to a target base stock level. The echelon inventory position of an end-item is defined as the sum of outstanding orders, physical stock minus customer backorders. The echelon inventory position of an upstream item is defined as the sum of outstanding orders, physical stock and the echelon inventory positions of its parent items. Clearly, in a supply chain under stochastic demand, there is no guarantee the item orders can be satisfied by its child items. Therefore, the echelon base stock policies are complemented by allocation policies that describe how available inventory of an item is allocated among the parent item orders. In real-life supply chains, such allocation policies are far from obvious, when parent items need multiple items, besides the item for which the allocation is decided for. In De Kok (2018) a class of policies is described, denoted as Synchronized Base Stock (SBS) policies, that provide a recipe for item order release in general multi-item multi-echelon systems, taking into account the need for allocation of available inventory. De Kok (2018) provides evidence of the empirical validity of the model proposed and its analysis.

The SBS policies were proposed in De Kok and Visschers (1999), and further elaborated on in De Kok and Fransoo (2003), where it was shown that SBS policies outperform rolling-schedule LP policies. The latter policies mimic the planning process predominantly used in practice, where periodically an order release plan is derived from solving a mathematical program that takes into account material and

resource constraints over some planning horizon, e.g. one year. The SBS policies have been implemented, as mentioned above, as a logic for planning in volatile environments.
In this extended abstract we propose and test a heuristic to extend SBS policies to the situation with item rejects. These item rejects constitute the medium- to high-frequency disruptions, and their impact is the scrapping of materials. We provide evidence that the heuristic provides accurate approximations of the performance of the system, measured as average inventories of items and the customer service levels of end-items. With this accuracy as a basis, we use the heuristic to develop “optimal” solutions, i.e. the average item inventories that minimize the sum of holding and penalty costs. We derive penalty costs by setting a non-stockout probability target and using the so-called Newsvendor fractile to determine the penalty costs (cf. De Kok (2018)). Our main finding is that the average inventories are insensitive to the reject rates, which generalizes the findings of Henig and Gerchak (1990) for single-item single-echelon systems to general multi-item multi-echelon systems. Clearly, the base stock levels that yield these average inventories depend strongly on these reject rates.
In the next section we describe the model assumptions. In section 2 we provide the main ideas behind the heuristic. In section 3 we present some representative simulation results that yield our main conclusions.

1. Model

We consider a multi-item multi-echelon system consisting of M items. The Bill of Material describing the parent-child relationships is given by (a_{ij}) with $1 \le i, j \le M$, i.e. a_{ij} is the number of child items i in one parent item j. We define L_i as the (constant) lead time of item i. Thus an order for item i released at time t is received in stock at time $t + L_i$. The demand for end-item k in an arbitrary period is denoted as D_k . We assume that the demand for end-items is i.i.d. Let $D_i(s,t]$ denote the echelon demand of item i during time interval (s,t], where the echelon demand is composed of the demand for all end-items that have item i as a child-item, corrected for the BoM relationships (a_{ij}). Finally, we define the item yield rate p_i, i.e. a fraction π_i of items ordered is approved for use. Then we define $R_i(s,t]$ as the number of items i rejected during time interval (s,t]. Regarding the modelling of yield, we can assume that each individual item is approved with probability π_i, or assume an order batch is approved with probability π_i. These different assumptions yield different yield processes, but the analysis sketched below is similar. W.l.o.g. we assume that items are approved on receipt in the item stockpoint.
Regarding the cost structure we assume linear holding and penalty costs. Under SBS policies it can be shown that each end-item k satisfies the Newsvendor fractile (cf. De Kok (2018)), i.e.

$$P\{X_k \ge 0\} = \frac{p_k}{p_k + h_k},$$

Where X_k denotes the stationary net stock of end-item k. Thus, if we set a non-stockout probability target, we can derive the underlying implied penalty cost per unit short.

2. Outline of analysis

The model described above is mathematically intractable, due to the natural autocorrelation in the reject process. Under a base stock policy, an item rejected at time t is ordered immediately, and is replenished at time $t + L_i$, where it can be rejected again with a probability π_i. Thus rejects at times $t + nL_i, n \ge 0$ are positively correlated. Besides that, the rejects depend on the order release quantity. In the analysis of multi-item multi-echelon systems without rejects, the order release quantities are unknown, yet the system can be analysed using the so-called balance assumption of Eppen and Schrage (1981).
It can be shown that for serial systems without upstream stocks and when a stockpoint can always satisfy its downstream demand, the order releases have the same distribution as the demand per period. We use the latter as our approximation assumption for general multi-item multi-echelon systems to derive expressions for the rejects during a time interval.
Let us define

$Q_i(t)$	Amount of item i ordered at time t
$R_i(s,t]$	Amount rejected of item i rejected during interval $(s,t]$

$R_i^{ech}(s,t]$	Amount rejected of items rejected in the echelon of i during interval $(s,t]$
$D_i^{eff}(s,t]$	Effective echelon demand for item i in time interval $(s,t]$
$N_{n,m}$	Number of subsequent failures of item m ordered at time $t-nL_i$
I_A	Indicator function of event A

Then we find the following set of equations that enable computation of the effective echelon demand process that we substitute for the echelon demand process in the system without rejects. By doing so, we can apply the approach described in De Kok (2018) to determine base stock levels for system without rejects.

$$D_i^{eff}(t-1,t] = \sum_{j\in V_i}\left(D_j^{eff}(t-1,t] + R_j(t-1,t]\right)$$

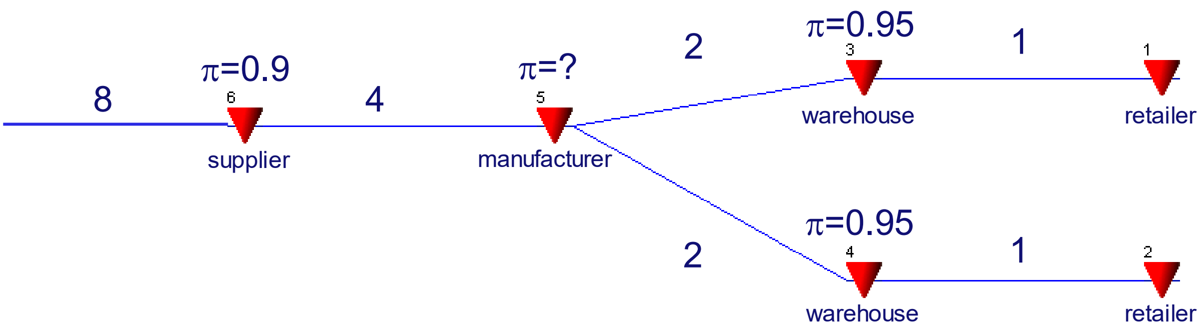
$$R_i(t-1,t] = \sum_{n=1}^{\infty}\sum_{m=1}^{D_i^{eff}(t-nL_i-1,t-nL]} I_{\{N_{i,n,m}\geq n\}}$$

$$R_i^{ech}(t-1,t] = R_i(t-1,t] + \sum_{j\in V_i} R_j^{ech}(t-1,t]$$

For general multi-item multi-echelon systems we need to synchronize the base stock levels of child items used in the same parent items. In SBS policies this is achieved by using the same base stock levels for these child items. However, the reject behavior of these child items may be different. We take this into account by increasing the base stock level for a child item with its average echelon rejects over its lead time. As the amount of echelon rejects during the lead time is stochastic, we must take into account that the actual amount of echelon rejects maybe higher or lower than its average. This yields an additional “shortfall” which can be both positive and negative, and is the maximum of the difference between the actual amount of echelon rejects and its average. As a consequence of the rejects, the synchronization aimed for fails, and additional *remnant* stocks emerge. We find that the average remnant stock of child items in the same parent is the same for all child items.

3. Results and conclusions

In section 3 we provided an outline of our analysis. In this section we present the results of a computational study for a divergent system. We restrict to such a divergent system, as the SBS policies derive the orders for a general multi-item multi-echelon system from one or more associated divergent systems (cf. De Kok (2018)). The 4-echelon system is depicted in the figure below.



The number on the line denote the lead time towards the stockpoint. We assume retailer demand per period has a mean and standard deviation equal to 100. Each stockpoint has an added cost of 1. We target a fill rate of 95%. We vary the approval rate p and optimize the system under SBS policies. The results of our experiment is given in the table below.

	sup, π=0.9		mfg		whs, π=0.9		ret, π=0.9		fill rate
π(mfg)	ana	sim	ana	sim	ana	sim	ana	sim	sim
0.6	287	282	188	180	81	85	372	376	0.951
0.7	306	302	151	140	79	81	370	372	0.948
0.8	318	313	130	123	76	79	374	374	0.947
0.85	321	316	123	118	76	78	374	373	0.947
0.9	324	320	118	114	75	77	378	377	0.948
0.95	326	322	115	112	75	77	378	377	0.947
0.99	327	322	114	111	75	76	378	376	0.947
1	327	322	113	111	75	76	378	376	0.947
perfect	316	313	113	110	74	76	378	376	0.946

We conclude that the heuristic outlined above yields quite accurate results for a system with approval rates lower than 1 at multiple levels. Furthermore we find that the optimal inventory levels at the downstream stages are insensitive to the changes in the approval rate at the manufacturer. Yet, the base stock levels determined by the heuristic are quite sensitive to the approval rates at the manufacturer. Thus we can state that the heuristic developed provides a means to analyze multi-item multi-echelon systems with random yield.

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Measuring and analysing resilience of interdependent STE systems
Resilient sensing systems for infrastructure monitoring

The Resilience of Vision-based Technology for Bridge Monitoring

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Summary

Robust monitoring of bridges is necessary to ensure its serviceability and traffic safety. A reliable sensing system to measure bridge responses is the key to such monitoring approaches. This research discusses the resilience of vision-based monitoring (VBM) for accurate and reliable bridge monitoring. VBM deploys cameras to capture the movement of bridges and uses suitable image processing algorithms to derive information on bridge health. VBM as a low cost and user-friendly monitoring system for accurate response measurement, simultaneous multiple target tracking and hardware adaptability is assessed based on literature. Measures to make VBM resilient in adverse field conditions are also discussed. Overall findings emphasise the accuracy and reliability of VBM for holistic and cost-efficient monitoring of bridges.

Keywords

Bridge monitoring; Computer vision; Structural health monitoring (SHM); Resilient sensing system; Vision-based monitoring (VBM).

1. Introduction

Bridges are important assets of civil infrastructure that enables mobility and has both economic and social significance. However, most of the existing bridges are ageing. For example, the majority of the currently operating bridges in Europe were built in the 1950s and are reaching the end of their design life (Gkoumas et al., 2019). With continuously increasing traffic loads, it is becoming increasingly important to monitor and maintain these ageing infrastructures. Recent tragic incidents like the Genoa Bridge Collapse (O'Reilly et al., 2018) further highlights the need for efficient bridge monitoring. Traditionally brides are monitored periodically through a visual survey of its accessible parts. Such visual inspections are subjective and susceptible to human error. Structural health monitoring (SHM) systems are more frequently introduced in bridge condition assessment. Robust and continuous measurement of bridge responses such as displacement, strain, etc. under applied loads (e.g., traffic load, temperature and wind) provide information on bridge performance. A general bridge SHM framework is illustrated in Figure 1. Bridge responses are measured with contact sensors such as a linear variable differential transducer, Fibre Bragg Grating sensors, etc. or non-contact sensors such as cameras. Response time-histories are analysed for anomaly such as damage in the bridge. Thereafter, bridge management authorities intervene in maintenance work, if required, based on the outcome of analysed data.

This research discusses the resilience of vision-based monitoring for accurate and reliable bridge monitoring. VBM is a non-contact, non-destructive system that measures structural responses using advances in camera technology and computer vision. These systems pose competitive advantages over contact sensors. For example, cameras can be found at low-cost; VBM is non-destructive, offers measurement collection of multiple targets, and has simple instrumentation and installation (Xu and Brownjohn, 2018). This abstract aims to analyse the performance of VBM for bridge response measurement in terms of accuracy, distributed monitoring, hardware adaptability and identifies means to make VBM resilient by addressing its limitations based on literature.

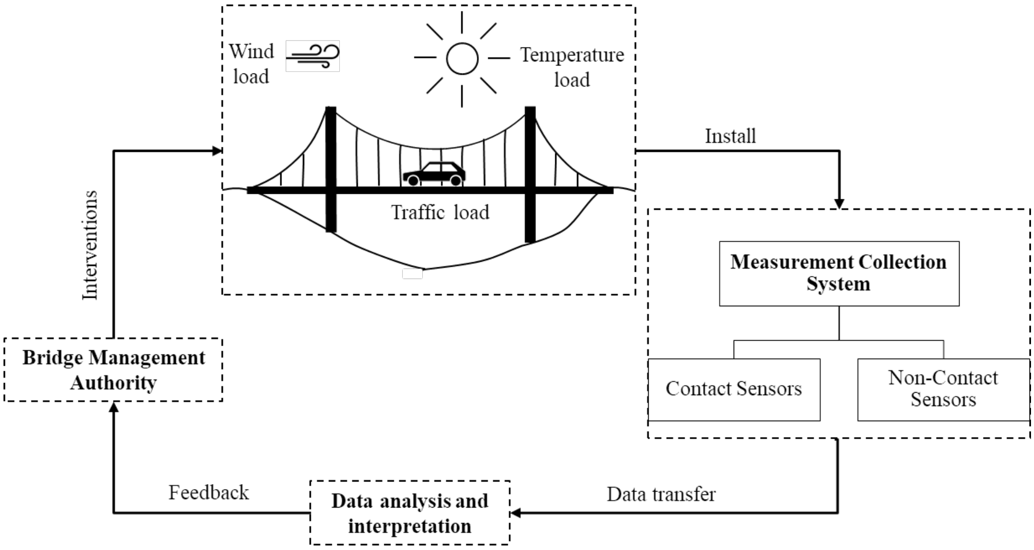

Figure 1: A general framework of Bridge health monitoring (Borah et al., 2020)

2. Vision-based monitoring of bridges

Vision-based monitoring (VBM) systems consist of hardware components such as cameras, lens, tripods, etc for image collection and image processing algorithms for measurement of structural responses. These are non-contact sensors and measure structural responses such as deflections and strain which are analysed for structural performance. Figure 2 shows a schematic arrangement of VBM used for monitoring the mid-span structural response of a truss bridge. VBM measures displacements of targets (structural features) under loading using suitable image processing algorithms (Feng and Feng, 2018). The targets can be natural targets such as bolts and nuts or artificial targets attached to the bridge. In Figure 2, sequential image frames, I_n (n = 0,1,2,3,…,n) of the mid-span joint are captured corresponding to time t_n (n = 0,1,2,3,…,n). t_0 represents the time of no loading. Position of targets in the sequential images is tracked over time to generate its displacement-time histories. VBM commonly uses the concept of digital image correlation to track the position of targets. Digital image correlation compares images of the structure in reference (un-deformed) and current (deformed) frames to provide full-field displacements and strains (Bing et al., 2009). The algorithms are a combination of suitable sub-pixel registration, template matching and camera calibration techniques. Template matching is the principal component of the algorithm. Commonly used template matching approaches are area-based matching, feature-based matching, optical flow estimation and shape-based matching. Structural responses such as strains and natural frequency are then derived from the measured target displacements (Brownjohn et al., 2017).

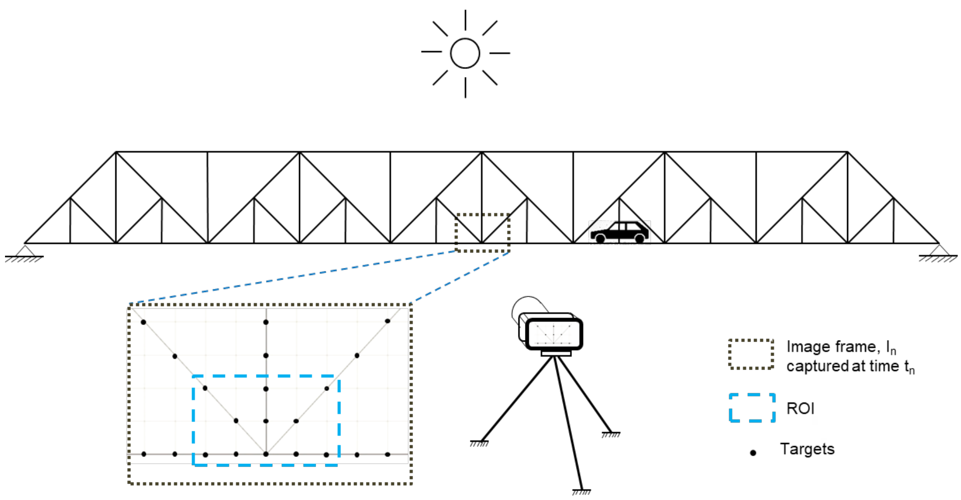

Figure 2: Schematic of a vision-based monitoring system

3. Resiliency of VBM

A resilient monitoring system provides accurate and reliable structural safety information with simpler instrumentation, minimal health and safety hazard and at optimal cost. It should also be able to sustain errors induced by environmental factors and mechanical malfunction in long-term monitoring. This section discussed VBM as a resilient monitoring system for bridge monitoring.

3.1. Accuracy

The measurement accuracy of vision-based technology is dependent on parameters such as camera-to-target distance, target pattern features, lighting conditions, camera mounting stability and video-processing methods (Xu and Brownjohn, 2018). Khuc et al. (2017) suggested a measurement accuracy of 0.04 mm based on a vision-based laboratory experiment in a short-range distance (<14 m). A sub-pixel accuracy of 0.5 to 0.01 pixel had been reported in algorithms used for vision-based monitoring (Bing et al., 2006). VBM system has shown promising evidence in providing reliable information on bridge performance such as its deflection profile, load carrying capacity, damage detection, vibration serviceability assessment, etc. (Dong and Catbas, 2020).

3.2. Distributed monitoring

Most contact sensor-based SHM systems require numerous sensors for distributed monitoring of bridges. However, multiple targets in the bridge can be tracked using a single camera or a combination of a few cameras in VBM. Lydon et al. (2018) developed a vision-based monitoring system using two modified GoPro cameras for distributed displacement measurement in Verner bridge, Northern Ireland. Kromanis et al. (2019a) created super-resolution images of the entire laboratory beam by stitching images captured by a robotic camera which can provide high-resolution data points for distributed monitoring of the structure. Xu et al. (2018) achieved measurement accuracy of ±0.037 mm for camera-to-target distance of 5.70 m using a GoPro camera fitted with a wide-angle lens to measure the displacement of several targets in a laboratory beam. Thus, VBM can enable holistic monitoring of bridges at a low overall cost and with simpler instrumentation.

3.3. Hardware adaptability

VBM system is adaptable with multiple camera types thereby facilitating a flexible and cost-effective monitoring system as per user's requirement. Lydon et al (2018) achieved high accuracy in measuring the displacement of a laboratory beam using a Nikon D180 (approximate cost £2500) as well as a modified GoPro (approximate cost £500) camera. Unmanned aerial vehicles are emerging hardware used in VBM to collect visual information of damages in structures (Perry et al., 2020). Moreover, promising accuracy of response measurement has been recorded by researchers using readily available advances in the in-built camera of smartphones (Kromanis et al., 2019b; Orak and Ozturk, 2018).

3.4. Making VBM resilient

VBM has easy instrumentation that can enable accurate distributed monitoring of structures at a low cost. The resiliency of VBM can be further improved by mitigating its common errors sources such as camera-movement, environmental factors, etc. Camera unsteadiness can induce an error in measurement, especially in long term field applications due to motion induced by wind, traffic vibration, etc. Camera-motion induced errors are usually compensated in VBM by using stationary objects in the background as a reference. Lee et al. (2020) proposed a dual-camera system where the main camera tracks the target and the sub-camera, tightly attached to the main camera, measured the 6-DOF motion of the main camera. Motion induced error calculated from the 6-DOF motion of the main camera compensated the error from 44.1 mm to 1.1 mm. The camera assembly is often sheltered in tents to avoid error due to wind in field implementations (Ribeiro et al., 2014). Environmental factors such as illumination level, fog, background disturbance can interfere with field implementation of VBM. Ye et al. (2016) encountered difficulty in pattern matching when the illumination level was below 75 lux and the vapour level was high. Such error due to bad weather can be enhanced by applying suitable image processing algorithms. Artificial lights are also used to illumination the targets (Ribeiro et al., 2014). Vasileva et al. (2018) successfully adapted VBM to sustain the extreme cold climate of Russia by incorporating an auto-heating unit and a drying cartridge in the camera unit.

4. Conclusions

Frequent monitoring and timely maintenance are crucial to ensure the serviceability of bridges and avoid catastrophic failures such as Genoa Bridge Collapse. Cameras and computer vision technology comprises the vision-based monitoring (VBM) system to provide accurate non-contact monitoring of bridges. This abstract evaluates the performance of VBM as a resilient monitoring system based on literature. Following conclusions can be drawn:

(a) Measurement accuracy of about 0.04 mm or sub-pixel accuracy of 0.5 to 0.01 pixel has been reported in the literature.
(b) The required accuracy of VBM has been achieved for simultaneous monitoring of multiple targets using one or a combination of a few cameras.
(c) The monitoring system is adaptable with a range of low-cost and expensive cameras, thereby enabling a flexible monitoring system as per users' need.
(d) The resiliency of VBM can be improved by incorporating innovative measures to eliminate common errors sources such as camera-movement, environmental factors, etc.

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Vision-based bridge monitoring using displacement curvatures

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Summary
Resilience is about improved operational performance and safety by ensuring integrity and redundancy of infrastructure systems. Structural health monitoring (SHM) of old infrastructure like bridges is crucial to ensuring resilience. The fusion of affordable vision-based structural health monitoring (VBSHM) systems with effective damage detection techniques has the potential to provide cost-effective solutions to support condition assessments of such old bridges, - a necessary step towards ensuring their safety and consequently resilience. With VBSHM, distributed sensing along a bridge is attainable, after which image-processing can be used to obtain bridge response. One of such responses is curvature. The curvature technique involves fitting a curve to response from tracked targets, extracting their quadratic coefficients across all loading timesteps, and taking the maximum coefficient as bridge response. Feasibility of this technique is demonstrated on a numerical model of a truck-loaded bridge girder subjected to multiple damage scenarios. Noise is also added to replicate real-world scenarios. Damages can be detected and localised but are influenced by damage extent and measurement noise. The technique shows potential for field applications.

Keywords
Resilience; damage detection; vision-based deformation monitoring; condition assessment; numerical modelling; signal interpretation.

Introduction (10 pt Arial Bold)
The concept of resilience, - from a civil engineering perspective, is mostly about improving structural integrity of systems. This is largely expressed through structural robustness and redundancy.
But to begin making any approach towards ensuring a resilient infrastructural system, already-built facilities such as bridges, regardless of their age must be given attention. They must be shored up to the level required of new infrastructure. 3,203 (4%) of bridges in the UK are deemed structurally unfit (RAC Foundation, 2017). There is no resilience if these don't get the interventions they need. The safety of these old bridges predominantly rely on regular visual inspections, which are time and labour consuming, and subjective (Brownjohn, 2007), and also the long periods between principal inspections (Highways Agency *et al.*, 2018) mean that faults can develop undetected. Sophisticated sensor systems employing fibre optic sensors, inclinometers, and strain gauges, etc. have been installed on important (and large) bridges, but they are cost-prohibitive so are not efficient for the small, old ones. Affordable vision-based systems consisting a camera and image-processing software provide an excellent solution to complement visual inspections for these bridges.
Applications of vision-based systems on bridges is nothing new (Feng and Feng, 2018; Xu and Brownjohn, 2018). Structural response is extracted from image frames using open source software (e.g., DeforMonit (Kromanis and Al-Habaibeh, 2017)), or others. Most studies have relied on single target measurements (Ribeiro *et al.*, 2014), but multi-target tracking has also been explored, albeit with limitations in achievable measurement resolution due to increased camera field of view (Kromanis & Forbes, 2019).).
In this research, curvature, - a damage-sensitive structural response is described, as well as a damage detection technique based on it. It is applied to structural response data obtained from vision-based monitoring. This has the potential to be an affordable condition assessment option for small to medium-scale bridges at risk, and which ensures structural safety, and resilience of our overall infrastructural systems.

Methodology
Consumer-grade cameras are used during bridge inspections to capture videos of a bridge subjected to known loads (e.g., truck or tram). Structural response along the bridge is computed from images using image processing techniques. The response at the first inspection is assumed to represent

baseline conditions of the bridge (r_0). In each new measurement collection event, structural response (r_i) is obtained and compared to the baseline response for bridge condition assessment.
Curvature is one of structural responses calculated from displacement data obtained from monitoring. The curvature (a) along any length of a horizontal structure for any image frame is the quadratic coefficient of the univariate quadratic function that best approximates its position or curve in a two – dimensional Euclidean plane. The quadratic approximation function is given:

$$f(x) = ax^2 + bx + d \qquad (1)$$

The quadratic coefficient (a) is taken from the equation fitted on at least three targets (T), covering a specified length of the bridge. This can be taken across bridge length using a moving window. a determines the degree of curvature of the resultant fit. At any timestep or image frame, the practical procedure for calculating curvature is described diagrammatically below:

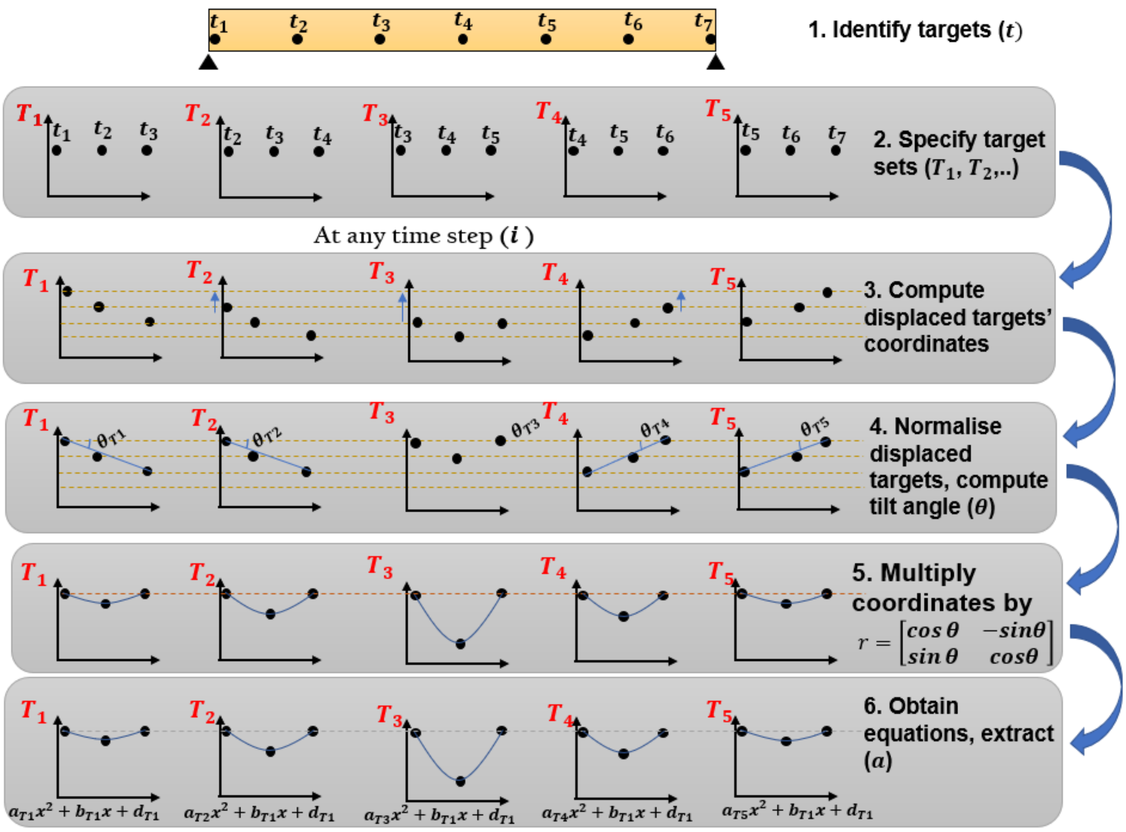

Figure 1: [Curvature obtention at any timestep]

The maximum curvature (a_{max}) at each target set (T) is extracted along the bridge length to form a maximum response curve, which is taken as the curvature response (r_c). Damage sensitive feature ($e_{c,i}$) is expressed as the ratio of the change in response (Δc_i) between any two inspections. Damage indicating threshold (γ) can be case-specific. Damage is located where e spikes.

Numerical validation

To validate the methodology, a numerical model of a typical reinforced concrete girder found in highway bridges is subjected to a load from a slowly moving 25 tonne, three axle rigid truck distributed between several girders. Damage scenarios are created by reducing the value of Young's modulus (S) of certain elements in location (D_i), or a combination of elements. These reductions in element stiffness (10%, 50%, and 100%) correspond to 2.5%, 12.5%, and 25% cross-sectional stiffness reduction (known as S_1, S_2, and S_3 respectively). Scenario S_1D_2, for example, denotes 10% reduction (S_1) of stiffness in the element located in D_2.
Different intensities of white noise are also added to target displacement response and analysed. Three noise levels ($N_i, i = 1,2,3$) are adopted. To recreate realistic measurement-collection, each of these noise levels is assumed applied to two different field-of-views (F_1 and F_2) hypothetically captured with a 4096×3072 pixel frame 12 MP camera. F_1 captures a small 2.4m length of bridge while F_2 captures

12m. Practically, the field-of-view (F) scales the noise intensity by F_2/F_1; so for example, with F_2 covering 12m bridge span, the effects of noise is amplified five times, and vice versa.

Results

Figure 2 below displays one of the results from the most severe damage scenarios in which damage is detected and localised. It can be observed that the measurements are also noisy, the noise in this scenario is aggregated from the maximum noise level (N_1) with the scaling effects from F_1. The red dashed lines indicate an arbitrary 5% damage threshold above which damage is said to be present. Due to the severity of the damage in this scenario, the response seems out of scale (i.e., way too large compared to the threshold). Damage is inferred from the fact that the threshold is surpassed, and located where it spikes.

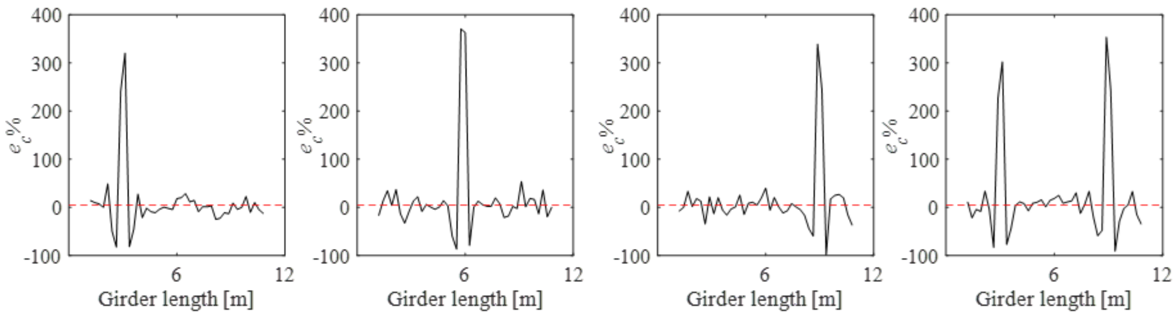

Figure 2: Damage located at several locations in the girder of 12m. the noise in this scenario is aggregated from the maximum noise level (N_1) with the scaling effects from F_1. The red dashed lines indicate a 5% damage threshold above which damage is said to be present.

Conclusion

This paper introduces a purely data driven, damage detection approach using displacement curvatures, integrated into a cost-effective vision-based bridge condition assessment scheme. The numerical study demonstrated that damages can be detected and located using curvature, for as low as 2.5% sectional stiffness loss without measurement noise, and 25% with measurement noise. The approach relies on the accuracy of the vision system which can be enhanced by addition of zoom lens, a smaller field of view which may imply the use of multiple, higher resolution cameras to cover more length. The approach shows potential for full-scale field use, and is already being deployed in an ongoing pilot study. It will also provide an affordable complement to visual bridge inspections for small to medium scale bridges. The contribution of this approach to infrastructural resilience is immense; - timely fault detection and structural performance information ensures that deficient bridges can get necessary interventions; and more affordable and less difficult bridge monitoring frees up funds for these interventions when required. At last, our long-neglected small bridges and footpaths can be safe and structurally sound, helping to ensure resilience for our roads and highway infrastructural systems.

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System representation of dependencies when developing intervention programs on infrastructure networks

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Summary
Considering dependencies between the assets of an infrastructure network when developing intervention programs can increase the resilience of the infrastructure. Existing literature lacks in a structured way how all the different dependencies and their effect on the costs of an intervention program are considered. In this work, a system representation is proposed that enables to represent the dependencies between candidate interventions and between the candidate interventions and the effect of the interventions on the provided service during the execution of the interventions when developing intervention programs on infrastructure networks. The representation using graphs enables the straightforward formulation of mathematical optimisation models that can be solved using global optimisation techniques. The use of a general intervention classification scheme and the definition of dependency rules between these categories allow the representation to be used for a combination of different types of assets, for different interventions and for different network topologies.

Keywords
Complex Systems, Dependencies, Intervention Programs, Network model, Infrastructure Management

Introduction
Resilient infrastructure requires an optimal intervention planning, where one major task is to decide which interventions, i.e. maintenance and renewal, to execute on which assets within an upcoming planning period and with which condition they are executed, i.e. during a complete shutdown of the system, during short shutdown periods, or under operation. These decisions are defined in intervention programs, whose determination requires to consider the dependencies between the interventions and between the interventions and the service provided in order to develop optimal intervention program. For the development of intervention programs, economical, structural, topological and resource dependencies are to be considered (Burkhalter & Adey, 2018; Dekker et al., 1997; Olde Keizer et al., 2017; Thomas, 1986). Thereby, economical dependencies refer to situations where the cost of executing multiple interventions differs from the sum of the execution cost for individual interventions. Structural dependencies refer to the situation where an intervention on one asset either implies or prohibit an intervention on another asset. Topological dependencies refer to the relations between the assets functionality and the system functionality. Resource dependencies refer to the limitations of resources that are shared among the interventions executed in an intervention program. In respect with intervention programs, the structural and resource dependencies constrain the possible combination of interventions selected. The economical and topological dependencies affect the costs of an intervention program, where economical dependencies have an effect on the costs on the asset level, i.e. the intervention costs, while the topological dependencies have an effect on the costs on the network level, i.e. the costs due to disturbed service, e.g. additional travel time in a transportation network. These two dependencies lead to non-linear cost functions on the asset and network level of an intervention program.

The existing literature in the field of optimising intervention programs use simple grouping (Furuya & Madanat, 2013; Van Horenbeek & Pintelon, 2013), graph theory (Hajdin & Lindenmann, 2007; Lethanh et al., 2018), two-step optimisation (Fecarotti & Andrews, 2018; Hankach et al., 2019; Kerwin & Adey, 2020), and use bi-level optimisation models (Lu et al., 2016; Ng et al., 2009; Zhang & Alipour, 2019) to consider some of the dependencies. The first three groups simplify the problem by considering simplified dependencies between the interventions and the effects on the service provided and by reducing the number of possible combinations for grouping interventions. The bi-level optimisation models are capable to consider detailed dependencies between the decisions on the interventions and the effect on the service provided. They cannot use global optimisation techniques and require heuristic optimisation models to optimise the intervention program. None of these approaches, however, has a clear and consistent structure how the different dependencies and their effects on the costs can be represented enabling to build straightforward optimisation models. Another group of research use reliability block diagrams, which are the most common and standardised representation of dependencies between assets functionality and the system functionality (Burkhalter et al., 2018; Pargar et al., 2017; Van Horenbeek et al., 2010). They are limited in considering economical dependencies in the asset level costs and in determining the combined network level costs of multiple interventions with different execution durations within the planning period.

In this work, a system representation is presented that models the dependencies between candidate interventions of an intervention program in respect to the costs of the intervention program. This enables the quantification of the costs of an intervention program during its execution and can be transformed into straightforward mathematical optimisation model.

System representation

The system representation considers the candidate interventions, i.e. the interventions that could potentially be executed within the intervention program, and their dependencies. The representation formulates a mathematical graph with two levels, i.e. the asset level and the network level, representing the effect of the dependencies on the two levels. The asset level is used to consider asset level costs when selecting the interventions of an intervention program, while the network level is used to quantify how the network operation is disturbed due to the intervention program and for how long it is disturbed. Figure 1 illustrates the concept of the representation with nine candidate interventions X_1 to X_9.

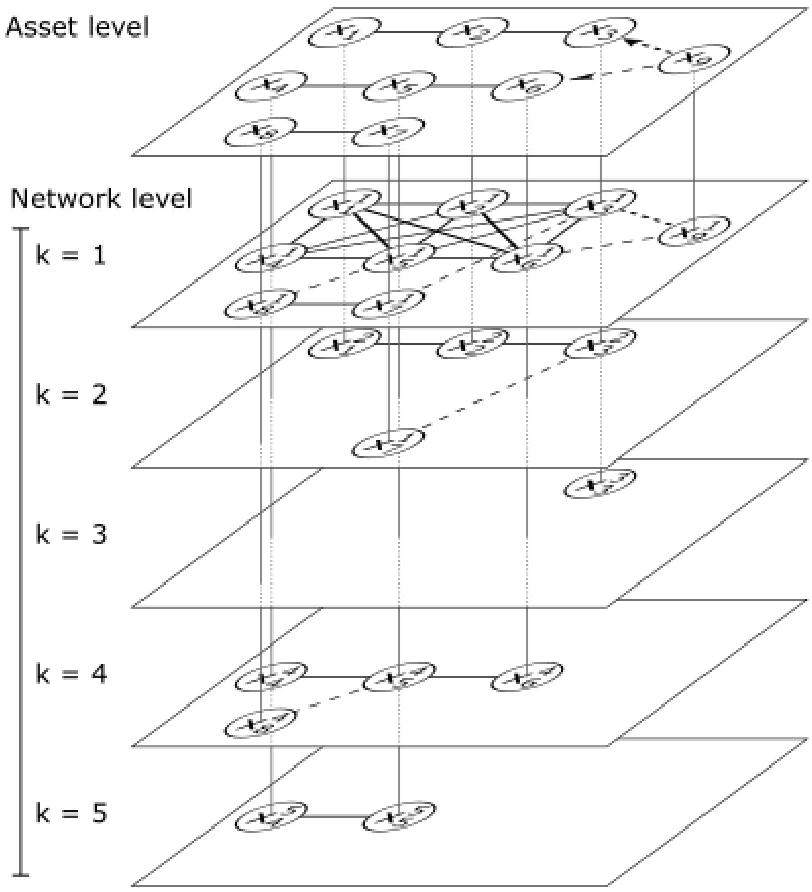

Figure 1. Level interaction

The asset level considers the candidate interventions and their structural and economical dependencies. It is represented by a graph $\mathcal{F} = (V, E)$ with the set of nodes V and the set of edges E. Each node $v \in V$ represents a candidate intervention $x \in X$. Each undirected edge $e^{ED} = (u, v) \in E^{ED} \subseteq E$ represents an economical dependency between two candidate interventions x_i and x_j represented by nodes u and v (sold lines in Figure 1). Each directed edge $e^{SD} = (u, v) \in E^{SD} \subseteq E$ represents a structural dependency between two candidate interventions x_i and x_j (dashed arrows in Figure 1). In the example in Figure 1, X_9 is structural dependent on X_3, while X_3 is economical dependent with X_2.

The network level is represented by a multi-layer graph $\mathcal{H} = (V, E, K)$. Each layer $k \in K$ represents a network state, which each defines a specific configuration of the service provided by the infrastructure. For example, a network state of a railway infrastructure could be the operation of a railway network with a single track closure on the double track line. A node $v^k \in V$ represents a candidate intervention x_i executed with network state k, i.e. x_i^k. An edge $e = (u^k, v^k)$ represents the requirement for sequential execution of two candidate interventions x_i^k and x_j^k represented by nodes u^k and v^k. For example, candidate interventions X_1 and X_2 have to be executed in sequence in network state 2.

The inter-level edges L ensure that the duration of each selected intervention is assigned to a network state with which it can be executed. An edge $e_i^k = (v_i, v_i^k)$ connects the candidate intervention node of the asset level v_i with its execution node in network state k of the network level v_i^k. The inter-level edges are illustrated in Figure 1 by the vertical edges from the asset level to the different traffic state layers in the network level. For example, the inter-level edge (X_1, X_1^2) relates the selection of candidate intervention X_1 with the execution of the intervention with network state 2 X_1^2.

Intervention categorisation

The system representation can be constructed for different situations, i.e. different asset types, intervention types and network topologies, using a structured and orthogonal categorisation of all candidate interventions and a set of rules regarding the dependencies between interventions of different categories. This categorisation requires considering the effect of an intervention on the systems functionality and the effect for other interventions. Table 2 shows the categorisation used for a railway network with intervention types I to V.

Table 2: Intervention categories

Category	Description	Example
I	Interventions executed continuously along the network, disturb the service provided, and hinder other interventions at the same location.	The renewal of a railway track executed with maintenance trains along the track.
II	Interventions on local assets disturbing the service provided within the proximity of the service provided, which hinders other interventions to be executed at the same location.	The replacement of a bridge in a road network.
III	Interventions outside of the proximity of the service that disturb the service provided.	Renewal of the controlling equipment on railway networks, which does not allow safe traffic operation.
IV	Local interventions in the proximity of the service without disturbing the service provided.	Filling cracks under operation of the road.
V	Interventions outside of the proximity of the service that do not disturb the service provided.	Vegetation management alongside the network.

Optimisation

The system representation presented enables to apply analytical and global optimisation techniques when optimising the intervention programs considering the dependencies between the interventions and between the costs of the interventions. The asset level can be transformed into a circular min-cost problem by introducing edges from a source node to all nodes of the asset level and from all nodes on the asset level back to the source node. The inter-layer relation can be modelled as an assignment problem dependant on the selection on the asset level. The network level can be transformed into a scheduling problem given the assignment of the selected interventions, where interventions connected by an edge within a network state can be seen as tasks that have to be executed in sequence without a specific order. In Burkhalter & Adey (2018), a constrained network flow model is proposed to combine these three problems into a single network flow problem that can be solved by common mixed integer linear programming, which is illustrated in Figure 2.

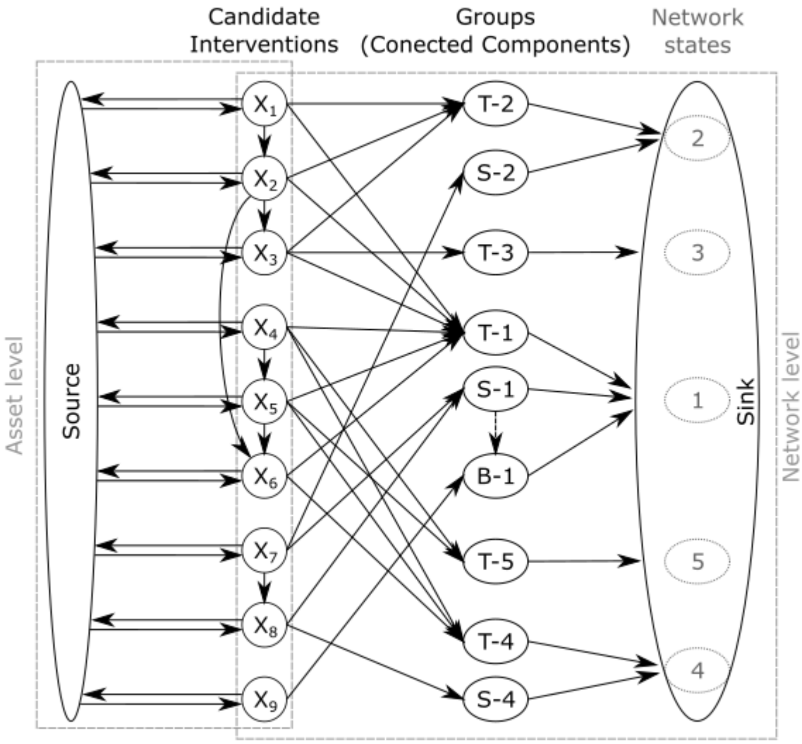

Figure 2. Network flow model as proposed in Burkhalter & Adey (2018)

Conclusion

The representation proposed in this work enables to represent the dependencies between the candidate interventions and the dependencies between the candidate interventions and the costs on the asset and network level when developing intervention programs. This representation allows formulating efficient optimisation models using network optimisation technics and integer linear programming. The use rules for the construction of the representation based on a general intervention categorisation enables the representation to be used for a combination of different types of assets and for different interventions.

Acknowledgements

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Determination of the Post-disaster Optimal Restoration Intervention Programs for Transportation Infrastructure

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Summary
The resilience of the transportation networks to an extreme event can be determined from the level of the service loss, and from the overall time and costs of restoring the networks to their original state. Resultingly, the selection of an optimal post-disaster intervention program can significantly contribute to increasing the resilience of the networks to extreme events. However, the determination of an optimal restoration intervention program is not a trivial task, especially when dealing with large networks. This paper proposes a mathematical model to determine the optimal restoration program for transportation networks, that minimizes the weighted sum of the direct and indirect consequences over the period between the occurrence of the disruptive event and the time the restoration work is complete. This model can be used for real-world networks considering various constraints on available budget and resources.

Keywords
post-disaster restoration programs; heuristic algorithms; road network resilience; optimal intervention programs; genetic algorithm

Introduction
The transportation infrastructure are required to provide specified levels of service; however, extreme events, such as floods, earthquakes, heavy snowfalls, etc., whose frequency of occurrence and severity may change due to climate change can significantly reduce this level of service. As the functioning of societies depends on the transportation of goods and persons, infrastructure managers are responsible for keeping the extent of these possible service disruptions to a minimum. This includes the development and adoption of strategies to minimize the time and costs of restoring affected infrastructure (when/if service disruptions occur) so that they once again provide an adequate level of service.
An optimal restoration program refers to the determination of the type and the sequence with which the damaged objects in the network are to be restored, so that they provide an adequate level of service, considering the overall costs, and the available budget and resources (Cavdaroglu et al. 2011).
Finding the optimal restoration program from a finite set of combinations of different interventions in time can be categorized as a combinatorial optimization problem. Algorithms for finding optimal intervention programs can be divided into exact and heuristic algorithms. An exact algorithm guarantees to find the global optimal intervention program while a heuristic algorithm will find a good (near-optimal) intervention program, although it might not be the best available one. Heuristic algorithms, however, have the advantage of having a shorter running time which makes them more suitable for post-disaster decision-making, i.e. deciding how networks should be restored considering the associated risks.
Although a proliferation of objective functions and heuristic algorithms are used in literature to determine optimal intervention programs (Chen and Tzeng 1999; Yan and Shih 2012; Vugrin, Turnquist, and Brown 2014), the models have not been investigated to be used in the real-world networks with larger than a dozen edges. This paper investigates the efficiency of the Genetic Algorithms (GA), in real-world post-disaster decision-making related to the selection of the optimal intervention programs.

The Algorithm to Find the Optimal Restoration Programs
The objective function of the model is to minimize the weighted sum of the direct and indirect costs, i.e. reductions in the cost of the restoration activities and also on the costs associated with the loss of service during the implementation of the restoration program following an extreme event (Adey et al. 2004).

$$min\ Z^R = \sum_{t \in T} \left[\sum_{n \in N^s} \sum_{i \in I(n|s)} \delta_{n,i,t} \cdot C_{n,i} \ + \ \gamma \sum_{p \in P_{od}^{s\backslash g}, e \in P} \Pi(t|x_{e,t}) - \Pi^0(t|x_{e,0}) + \sum_{p \in P_{od}^{g}} \Lambda(\mathrm{t}) \right] \quad (1)$$

where for each damaged object $n \in N^s$, only one intervention $i \in I(n|s)$, can be assigned at the time $t \in T$. A binary variable, $\delta_{n,i,t}$, has the value of 1 if, at the time t, the intervention i is executed on the object n with a damage state s; otherwise, the value would be equal to 0. The overall costs of intervention i on object n with a damage state s, i.e. $C_{n,i}$, is the summation of the fixed, variable and resource-related costs. Indirect costs are either due to the travel prolongation $\Pi - \Pi^0$, or are associated with the impassable paths and loss of connectivity Λ, and are estimated to be the difference between the indirect costs at time t and $t = 0$ when the extreme event had not yet happened and the network was fully functional. $P_{od}^{s\backslash g} \subseteq P_{od}$ is the set of od-paths with some possible flow and does not contain any objects with zero functionality g. Moreover, the link flow $x_{e,t}$ in Eq.1 is estimated by solving a user equilibrium assignment as indicated in Eq. 2:

$$x_{e,t} \ \in \min Z^T = \sum_{e \in \varepsilon^s} \int_0^{x_{e,t}} C_e^T(\omega) d_\omega \quad (2)$$

where C_e^T presents the cost-flow relationship. As indicated above, the determination of an optimal restoration program for transportation networks after the occurrence of an extreme event can be categorized as a multilevel optimization problem, where some variables of the objective function are constrained to the optimal solution of another part of the model. In this study, the minimization of the overall intervention costs, i.e the upper-level optimization in Eq.1 depends on the traffic assignment, i.e the lower-level optimization problem in Eq.2.

The upper-level optimization can be classified as a combinatorial optimization problem, where the optimal restoration program is selected from a finite set of combinations of different interventions in time. The classical optimization methods cannot be used for the upper-level optimization due to the computational complexity, nonlinearity, non-convexity, and non-differentiability of the problem (Hackl, Adey, and Lethanh 2018). Instead, Genetic Algorithms (GA) is used to determine the type and sequence of restoration intervention programs for transportation networks following the occurrence of an extreme event. The lower-level optimization which is embedded in the GA, i.e. the traffic assignment, is solved using a conjugative direst Frank-Wolfe algorithm.

The Case Study

The above-introduced model was used to develop a near-optimal restoration program after an extreme flood event on a part of the road network around the city of Chur, in Switzerland. In total, the network consists of 2,153 objects, including 2,011 road sections and 116 bridges.

Evaluation of the damage level following a natural hazard is normally done by performing inspections, however, due to lack of available damage assessment data in the area of investigation, the damage states of the objects in the network were estimated using fragility and capacity loss functions (Lam and Adey 2016), which were used in a flood simulation with a 500-year return period (Hackl et al. 2018).

The results of the flood simulation determined that out of 2,153 objects (roads and bridges), 20 road sections would be in state 1 with minor damage, and 4 road sections will completely lose their capacity and would be in state 2. The numbers for bridges are 3 and 2 for minor and major damage states respectively. Hence, a total of 29 objects need to be restored. Table 1 summarizes the restoration model that was used for this study.

Figure 1 illustrates the development of the restoration programs over time, which is attained through solving the bi-level optimization problem introduced earlier. On the upper part of the figures, the accumulated direct and indirect costs and their components, including fixed, variable, resources, travel time, vehicle operation, and lost connectivity, are presented. In the middle, the figures provide insights on the restoration schedule for the work crews A, B, and C over time and at the bottom of the figure the functional losses (loss of connectivity and additional travel time) of the network over time are illustrated. It can be observed that the economic costs due to loss of connectivity are mainly caused by B1, while object B5 causes the highest additional travel time. Consequently, restoring these objects yields the largest net improvement.

Table 1: Intervention types and associated recovery rates, resources and costs for road sections and bridges, adapted from (Hackl, Adey, and Lethanh 2018)

Object	State	Intervention type	Capacity recovery (%)	Duration (1)	Required crews	Fixed costs (2)	Variable costs (3)	Resource costs (4)
Road	1	Level 1	100	1	2	5.25	22	0.5
		Level 2	100	3	1	3.5	16.5	0.5
		Level 3	30	3	1	3.5	14.5	0.5
	2	Level 1	100	6	2	14.4	110	0.7
		Level 2	100	12	1	9.6	82.5	0.7
		Level 3	10	10	1	9.6	78.5	0.7
Bridge	1	Level 1	100	20	2	16	24	0.9
		Level 2	100	40	1	10	15	0.9
		Level 3	20	35	1	10	13	0.9
	2	Level 1	100	90	2	48	64	1.2
		Level 2	100	160	1	30	40	1.2
		Level 3	10	145	1	30	37	1.2

Note:
Duration: $\frac{hours}{element}$ for bridges, $\frac{hours}{1000\ m2}$ for roads
Fixed costs in $1000\ mu$
Variable costs in $\frac{1000\ mu}{element}$ for bridge; $\frac{mu}{m_2}$ for road
Resource costs in $\frac{1000\ mu}{resource\ crew\ hour}$

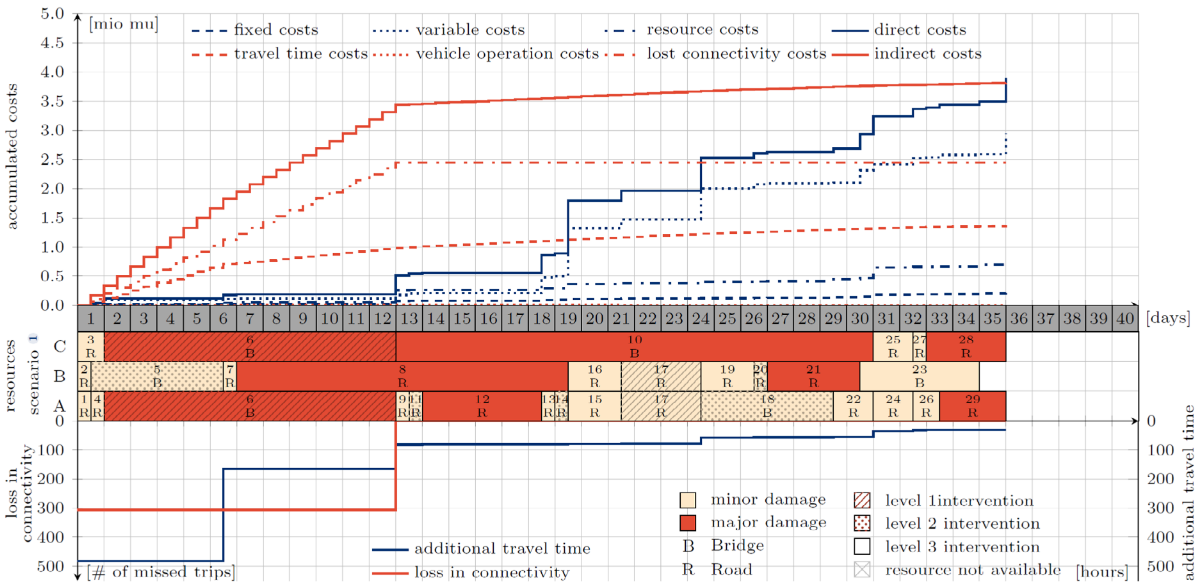

Figure 1: Development of the restoration program over time

Conclusion

This paper presented a model to determine the optimal restoration intervention programs for transportation infrastructure. The introduced model minimizes the total sum of the direct and indirect costs of restoring the network and has the flexibility to be used in real-world situations and for a variety of infrastructure types.

The presented model can be beneficial for infrastructure managers who are in charge of the determination of the resilience of critical infrastructures to extreme events. It can also provide estimations on the time required to restore the desired level of service following an extreme event and provide insights on various possible restoration programs and the trade-offs between the direct and indirect costs.

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Measuring and analyzing resilience of interdependent STE systems
Quantifying, measuring and monitoring resilience of systems

The ontology of resilience: The Impossible Trinities

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Summary
To address many societal challenges it is important to improve the resilience of the food system. Research is needed to quantify and analyse the resilience of food systems in different contexts. Is it possible to have a standardised description of resilience of a food system with a measurable set of indicators? To address this question we started by developing an ontology of resilience for food systems based on literature study and using insights from semantic technologies. Our exploration identifies a number of impossible trinities in resilience research on which choices must be made in the definition and measurement of resilience. Our findings are relevant to policy decisions in choosing the proper 'type' of resilience and researchers to identify the relevant research problem.

Keywords: resilience ontology; impossible trinities; trilemma; resilience policy

Introduction

Within the resilience debate, there is often confusion and contestation about what exactly is resilience, how can we measure, and how can different disciplines discuss this concept and ideal in a balanced and coherent way. There is a lot of terminology, disciplinary baggage, and those working on resilience to talk across one another. Ecologists, social scientists, economists, and policymakers, all bring their own views, interpretations, and values to the debate, and their stiff background and understandings cause rifts in the discussion, thus often stifling progress.
This paper provides a multidisciplinary evaluation of the literature to identify common themes and concepts that prevail in a broad analysis of the topic. In our view it will provide a valuable contribution to the resilience debate within and beyond food systems, by exploring the ontology of food system resilience. It aims to provide a multidisciplinary analysis that will allow academics and policymakers to identify the most significant themes and topics for discussion in the debate, attempting to bridge the gap between different disciplinary divides. While we only focus on one application of resilience, namely, food system resilience during extreme events, we believe that our approach and findings could be integrated and applied to other areas of resilience, as well.

Ontological explorations of resilience

The large number of definitions of resilience in numerous publications suggests that the importance of defining the resilience concept has long been recognized by scholars and practitioners alike. The publications on resilience and therefore the definitions of resilience have so proliferated that it becomes necessary for researchers to review the definitions regularly (Adger, et al., 2012, Anderson, 2015, Bahadur, et al., 2013, Béné, 2020, Bhamra, et al., 2011, Brand and Jax, 2007, Chandler, 2014, Klein, et al., 2003, Marston, 2015, Maruyama, et al., 2014, Thorén and Persson, 2015, Urruty, et al., 2016, Walker and Cooper, 2011, Xu and Marinova, 2013).

Generally acknowledging the appeal and elusiveness of the concept, a large number of authors have intended to 'unpack', 'discuss', 'conceptualize', 'clarify' or 'redefine' the concept using different perspectives (for example, 'holistic', 'integrative', 'practical', 'ecological', and 'social') and for various purposes (for example, 'understanding', 'measurement', and 'improving'). This further adds to the diversity of the definitions and expands the topics relevant to the concept. A universally accepted answer to the question 'what kind of thing is resilience' as addressed in Anderson (2015) is still wanting.

An insightful response to this question is the study by Olsson et al. (2015). Recognising the concept of resilience as still being elusive and in need of structuring, they suggested a typology of resilience organised around two conceptual meanings on one axis and two attributes on another axis. This results in four broad definitional categories as shown in Table 1.

Table 1: Typology of resilience, source: (Olsson, et al., 2015)

Meanings	**Attributes**	
	Descriptive- neutral (N)	**Prescriptive- good (G)**

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Quantifying, measuring and monitoring resilience of systems

Bounce back (BB)	**BB-N**	**BB-G**
	Holling (1973) The stability of ecosystems	Perrings (1998) Resilience for sustainable development
Bounce back and transform (BBT)	**BBT-N**	**BBT-G**
	Walker et al. (2004) Adaptations and transformations in social-ecological systems	Folke et al. (2010) Resilience thinking for transitions

This table illustrates that while the range of viewpoints about resilience definitions vary, there is a lot of overlap and they typically fall within one of these quartiles. Olsson et al.'s (2015) literature analysis also showed that the definitions of resilience by social scientists and natural scientists often differ in the following aspects:

1) System ontology[1];
2) System boundary[2];
3) The existence of multiple equilibria, thresholds, and feedback mechanisms[3];
4) Self-organisation[4]; and
5) Function and functionalism[5].

This suggests that it is difficult to reduce resilience to a single definition. A close examination of the implied system ontology underneath various definitions of resilience shows that resilience can never be reduced to a property of one entity alone -- it can only exist in a relation (the resilience of A to B) (Chandler, et al., 2020).

Trilemmas and strategies

In developing the ontology for food system resilience, we have identified several challenges that take the form of 'trilemmas' (also known as 'impossible trinities'). These trilemmas create theoretical tensions and methodological barriers in interdisciplinary research. The notion of trilemmas has a long history, originating in many different areas to refer to a trinity of issues, where there is often a trade-off because of their relative incompatibility. In the context of food system resilience, we identified the three types of issues to be addressed: system integrity, system transformability, and agency of individuals. Two of the trilemmas deserve special attention research projects aiming at providing policy advice, as we believe that we can add a valuable contribution to the research and practical implementation of such issues.[6] The first one concerns the operational definition of food system resilience. The second one deals with the challenges in resilience research.

[1] System ontology refers to the different perspectives on the formation and way that we can analyse systems. For example, some ecologists view systems as predator-prey relationships, whereas others view systems as an exchange of processes, functions, and energies.
[2] System boundary refers to the difficulty of establishing how to determine the parameters and bounds of a system. Because of the interrelated and mutual dependence of open systems, it is very difficult to clearly classify distinct boundaries and differentiating multiple interacting systems.
[3] This refers to the somewhat unknowable nature of systems and what their state of equilibrium is, what happens when it is crossed, and transitions between different states.
[4] Resilience theory is grounded in systems' complexity and the ability of systems to be able to self-organise and function.
[5] Function refers to the adaptation abilities, goal attainment, a system's ability towards integration and latency. In ecology, it refers to the ecological processes that allow the structure and ecosystem services to maintain.
[6] We note here that system transformability is the third factor in the trilemma, which we feel is too difficult to effectively and coherently model. There is too much room for error, potential for discrepancy, and impossibility to effectively model because of the diversity and chaotic nature of system transformability.

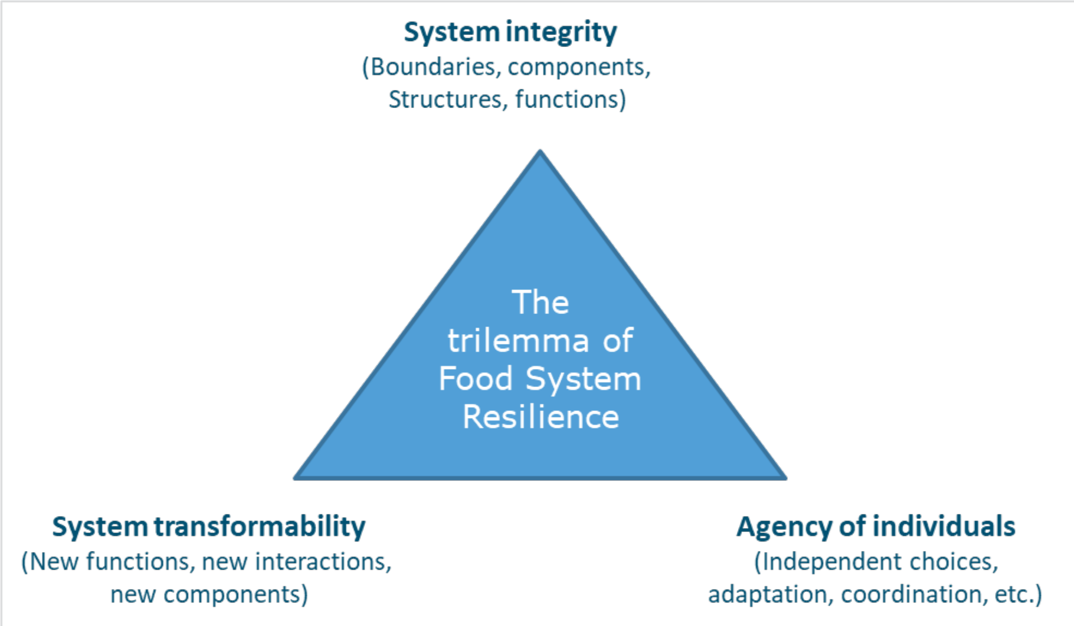

Figure 1: The trilemma of defining food system resilience and feasible options

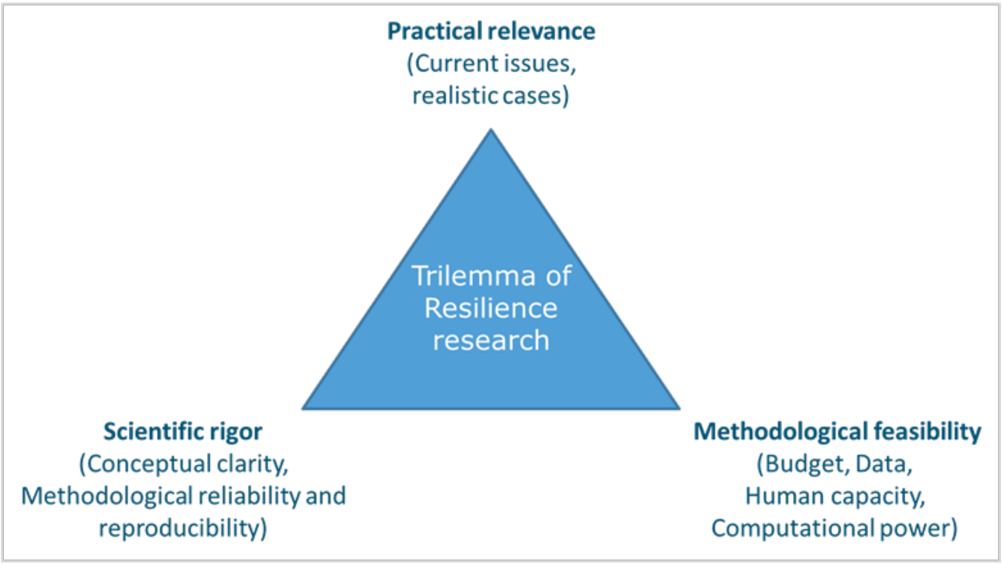

Figure 2: The trilemma of research on food system resilience

Conclusion

Our ontological exploration shows that resilience is a rich concept that has an important bearing on many themes and topics in domains such as food systems. This makes it highly relevant to develop and apply the concept of 'food system resilience'. The application of the concept in research and practice however faces many challenges that are rooted in ontological and epistemological differences among different disciplines and practices. While posing serious challenges in interdisciplinary collaboration and communication, these challenges also foster new research opportunities as knowledge gaps are discovered. For example, there is a need to critically investigate the social, environmental, and economic trade-offs implied in policy strategies towards resilience at various levels of food systems.

Researching resilience in any domain is a balancing act among scientific rigour, methodological feasibility, and practical relevance. Achieving conceptual clarity as required by scientific rigour may render the research methodological infeasible due to data and budget constraints and therefore

undermine the practical relevance of the research. Furthermore, the impossible trinities in the domain of food system resilience now engage the core of social sciences: trade-offs, power, agency, and governance at various levels. In evaluating policy options and strategies, political ideologies and moral considerations may interfere with scientific rigour and should be made explicit in research findings.
Interdisciplinary communication between the social and natural science can be difficult and divisive. The ambition to unify the theory may be counterproductive in addressing practical problems that often require multidisciplinary collaboration. The challenge is to identify context-specific problems and policy options using the 'resilience lens' and translating the concept into measurable indicators.
The ontological differences and debates are unlikely to be resolved anytime soon, nor should it be a priority for applied researchers to resolve these differences. If the research team aspire to address empirical problems, a pragmatic case-specific approach should be adopted to finding solutions while taking into account ontological differences.

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GOVERNANCE SYSTEMS AND INSTITUTIONAL ARRANGEMENTS FOR STE RESILIENCE

TRACK D

Uncertainty in urban planning: A framework for long-term climate resilience in complex urban environments

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Summary
Increasing urbanization in the light of climate change is putting a high concentration of people and urban systems at risk. Under such situations, any planning decision creates path-dependencies that has long-term impacts on urban growth. Hence, conventional, linear urban planning is proving inadequate to account for uncertainties and dependencies. To account for the long-term, urban planning must adapt to evolving climate variables. This means identifying appropriate spatial decisions for urban systems at the right time to reduce undesirable impacts from climate. In this study, we present a spatio-temporal framework to allow urban planners to systematically assess the full range of climate and related variables that impact urban systems. The framework then guides planning actions based on the inherent properties of the urban system. The aim of this study is for urban planning to move from a conventional risk-based approach to an uncertainty-oriented approach by bringing together concepts from urban resilience, layer approach and complexity theory.

Urban planning; Urban resilience; Climate Adaptation; Resilient cities; Socio-ecological systems

Introduction
As climate hazards evolve with fair uncertainty, there is an increased momentum globally to make strategies for urban resilience. Among many examples are the Rockefeller Foundation's City Resilient Framework (Index, C.R., 2014), Climate and Disaster Resilience Index (CDRI), several operationalization frameworks by global organizations such as UNDRR, ADB, ASEAN, UNFCC along with a significant body of academic literature (Jabareen, Y., 2013, Abdrabo, M.A. 2015. Crowe, P.R.,2016. Ribeiro, P.J.G., and Gonçalves, L., 2019). While these streams of work are making significant contributions to the urban planning and climate resilience discourse, a review of the strategies reveals a vast variation in the approaches adopted, variables considered, infrastructure prioritised, etc., that is bringing in inconsistency in practice.

Since integrating climate resilience in planning is a relatively novel concept, cities implement projects on a small to medium scale to achieve fast results or as a proof-of-concept. There are dedicated efforts in the domains of water management (Sao Paulo Water Ring, Rhine river), blue-green master plans (Copenhagen cloudburst strategy), flood control (dikes, dams), nature-based solutions (wetlands, sand dikes) and multifunctional spaces (floodable public plains, underground reservoirs, parking garages). There are exceptions in large-scale standalone projects like Room for the River, Bangladesh Delta plan, Maeslantkering storm surge barrier, etc. However, neither the small nor the large projects are integrated into the long-term development agendas of the region (Henriquez, L. and van Timmeren, A., 2017). Climate is an additional item, and the focus remains on managing probability-based risks and not on evolving uncertainties that plague decisions of the future.

Gaps
Despite the accumulated literature in urban climate resilience, there is a surprising absence of research that examines an approach to account for relevant variables for long-range planning irrespective of the actors involved. We can trace this back to the two crises in planning theory:

1. The first crisis arose from an emphasis on a techno-rational approach in planning that promotes creation of a static masterplan for the 'here and now' as opposed to the future (De Roo, G. and Hillier, J., 2016.) This continues to be a norm in all city master plans and visions that are developed for 5 to 20 years. This time period naturally prioritizes quantifiable, urgent development needs over the perceptibly unlikely climate uncertainties. However, investments made during this time will face uncertain and higher intensities of climate for which they may not have been originally designed for.

2. The second crisis arose because of an increased focus on communication where planners seek a 'negotiated' or 'agreed certainty' rather than facts or models which may be too complex. This continues till date against the backdrop of pressures from the actual world such as politics and power dynamics which may cause the values and preferences of planning actors to fluctuate. In addition, there will be a variation in the level of knowledge among actors that may not always be in the interest of the larger goal (Alfasi, Portugali 2007).

Most urban planning falls in the 'fuzzy middle' between the techno-rational and communicative approach (Schönwandt, 2007). Model-based decision support tools try to bridge this gap by allowing planners to build scenarios for better decision-making (Walker, W.E., Haasnoot, M. and Kwakkel, J.H., 2013). But these tools are data-intensive and do not consider the constraints of the urban planning process, making it difficult for planners to comprehend or use these models.

Objective

Building flexibility in the planning process to adapt to long-term uncertainties while meeting development goals will require a continuous integration of new and evolving climatological variables, socio-economic insights, and related uncertainties (Campbell, Heather, 2006). Relevant projects must be scaled up and integrated across the city/region. To implement this, the objective of this study is to develop a spatio-temporal framework that guides urban planners to systematically identify the full range of variables that impact urban systems and map planning responses. The focus will be on climatological variables and related socio-economic, environmental and technological variables.

Approach

The notion of resilience in a complex urban system is based on its capacity to evolve and consolidate into an implementable plan. Planners need to capture and manage the spatial dynamics to bring in potential flexibility in the plan and the planning process. This means identifying appropriate spatial decisions for urban systems at the appropriate time to reduce impacts from climate. The temporal aspect must account for: (1) the life cycle of the urban system, which determines which actions are needed (can be flexible and change its character/function); and (2) the urban planning timeframe, which determines how to prioritize those actions. Towards that, we will base the framework on 2 pillars (see Figure 1):

1. The 'Layers Approach' which classifies urban systems into groups of spatial elements with their own time rhythms of change (Frieling et al. (1998), Schaick, J., Klassen, I (2011));
2. The properties of Complex Adaptive Systems to improve the adaptive capacity of urban systems to climate variables (Roggema, R., et al, 2012).

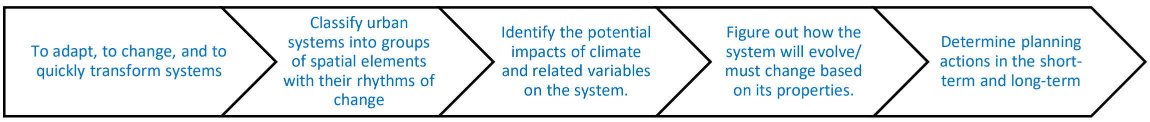

Figure 1: Research Approach

While this study will start with an overview of global literature, we will design the framework keeping in mind two cities of increasing complexity: Amsterdam Metropolitan Area (MRA) and Mumbai Metropolitan Region (MMR).

Methodology

To reduce complexity, planning theory has ignored the aspect of time, which automatically ignores the process of change (De Roo, G. and Hillier, J., 2016). In our methodology, we add the temporal dimension to the framework that integrates the urban planning timeframe and the life cycle of key urban systems to determine planning actions over 100 years. Towards this, we use the following steps:

Step 1: Review of literature at the intersection of urban planning and climate resilience to analyze existing frameworks of planning under climate uncertainties and identifying the range of variables and urban systems considered. We will use the DPSIR framework (used by the European Environmental Agency (EEA)) to establish the causal links between different urban systems and climate uncertainties (Svarstad, H.,et al. 2008, Kristensen, P., 2004, Carr, E.R., et al. 2007).

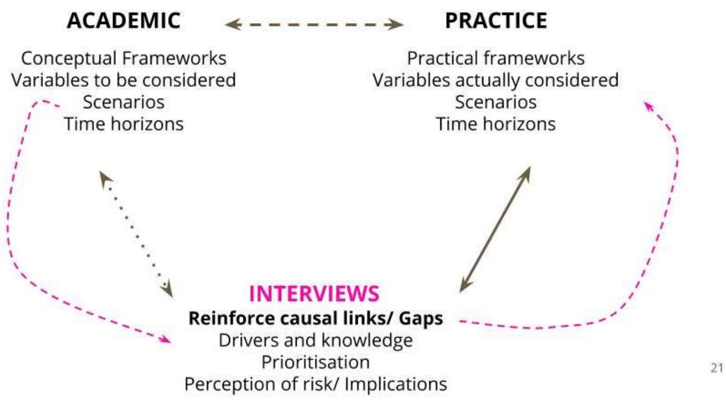

Figure 2: Research methodology

Step 2: We compare the variables proposed by literature to what is adopted in urban planning practice. We augment the findings with interviews from planning researchers and practitioners to establish the reasons for the gaps (see Figure 2).

Step 3: We use the findings from Step 2 to develop the spatio-temporal framework. We use the Layers approach and map the impacts of climate variables on each layer. We associate each layer with an urban system (including its spatial and temporal dimension) which will determine its potential to adapt.

Step 4: Once we establish the impacts, we derive the potential actions for adaptation using the properties of the urban system (derived from theories on complex adaptive systems). These are used to present directions to determine planning interventions to mitigate or adapt to these impacts. This starts presenting an indicative framework for planning practitioners as they must outline urgent development needs in the short-term while keeping in mind long-term goals.

Results and Conclusion

The usefulness of this framework lies in centralising the temporal aspect in urban planning. We match climate impacts to urban systems and their life cycles to determine planning actions (see Table 1 below). This is a key step in building an evidence-based system to account for long-term climate goals while meeting short-term development actions. The framework helps to connect the spectrum of uncertainty with embedded flexibility of an urban system. It contributes to the urban planning discourse by making first steps in enabling the adoption of an uncertainty-oriented approach to planning as opposed to the risk-based approach adopted in practice. The study presents a way to understand the uncertainty space in urban planning such that urban planners have a way to navigate through variables, their relations, and decide how to prioritize and integrate climate resilience goals while setting out master plans.

Table 1: The Conceptual Framework linking urban system layers to their properties to determine Planning Actions

Urban Layers (Roggema 2012)	**Life Cycle**	**System properties to improve adaptive capacity** (various sources) 1. *Emergence* 2. *Co-evolution* 3. *Self-organisation* 4. *Self-healing* 5. *Flexibility* 6. *Diversity* 7. *Agility* 8. *Co-existence*	**Planning Actions**
Natural resources (reserves, source of food, water, energy)	(20-100 years)	Self-healing Flexibility Diversity	Preserve Space for flooding Adaptive islanding Isolation etc.
Networks (transport, water, ecology, energy)	(10-100 years)	Emergence Co-evolution Self-organisation Agility	Heterogenous functions New patterns
Focal points (public space, landmarks, interchanges)	(5-10 years)	Emergence Co-evolution Self-organisation	Easy flows Preserve New patterns
Emergent occupation patterns (living environment)	(3-10 years)	Self-healing Flexibility Diversity	Safeguard New standards Space for flooding Adaptive islanding Isolated entities Functional mix
Unplanned space (parks, spaces around focal points)	(1-10 years)	Emergence Self-organisation Flexibility	Inundation Temporary occupation

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Resilient design as a driver of economic growth, livability, and solutions for local socioeconomic threats

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Keywords
Resilient design, economic growth, livability, wicked problems

Abstract
Communities throughout the world generally have not been developed to be ecologically resilient, despite their increasingly severe and disruptive impacts on socioeconomic. The triple interrelated ecological resilience threats of climate change, biodiversity, and resource scarcity must be addressed by communities at both regional and local scales, in ways that simultaneously resolve local socioeconomic threats, in order for communities to survive and thrive in the 21st century.

Yet current resilience solutions are typically developed at the local community scale, without consideration of the essential larger regional interdependencies, opportunities, and impacts. They tend to be reactive to specific threats, rather than comprehensively addressing the diverse interrelated ecological resilience threats they face, and they tend to be developed in a vacuum, without integration into regional socioeconomic development plans and systems, and typically irrespective of the local urgent socioeconomic threats that must be addressed to successfully develop resilient communities.

Multiscalar resilience strategies collaboratively developed at both the regional and local community scales, which proactively address potential ecological threats in holistic ways that directly address local and regional socioeconomic threats, can be substantially more effective and less costly. They can reduce municipal and regional operating budgets, and substantially improve local economic development and stability, and residents' well-being and lifestyles. Due to their holistic and local approach, effective solutions are highly contextual. Nevertheless, effective case studies, such as those presented in this paper, can demonstrate effective approaches and solutions that can inform solutions for regions worldwide.

D. Governance systems and institutional arrangements for STE resilience
D.s14. Top down or Bottom Up? Planning approaches and Collective Action for Resilience

Developing the ART of Resilience in a National Electric Utility

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Summary
The Enterprise Resilience team in Eskom, South Africa's national electricity utility follows top-down and bottom-up approaches to enhance resilience in their system. This system is a complex adaptive socio-technical organisation, situated within the context of an electricity sector in transition, as well as deep turmoil in the associated socio-economic, socio-ecological, and socio-political systems in the country. The heuristic used by the team is of developing the *"ART of resilience"*, which relates to the ability to *"anticipate and adapt, respond and recover, and to transform".* The metaphor of *art* intentionally references the complex adaptive processes involved in the production of art – which are seldom about the application of rules and more often about working with the affordance of the context in the moment. The intent is create conditions for beneficial emergence across various kinds of human networks internal and external to the organisation, namely formal (day-to-day) structures, emergency response structures, and informal networks.

Keywords
Resilience of complex adaptive socio-technical system; systemic change; stimulate emergence.

Introduction
The lived experience of dealing with increased levels of surprise and disruption, as well as recognition of our global interconnectedness - revealed by the COVID-19 pandemic - has underscored the need to translate resilience thinking into practise. Resilience thinking is an approach to build resilience in complex systems based on complexity thinking (Simonsen et al., 2015). A complex adaptive system that is resilient has the dynamic ability to persist, adapt and transform at multiple scales and timeframes in the face of persistent and disruptive change, (Folke et al., 2010; Walker et al., 2004). Whilst resilience thinking is prevalent in academic circles, ways to apply it in boardrooms and at the frontline of organisations is of importance to resilience practitioners in essential service sectors undergoing disruptive change.

Resilience literature distinguishes between two types of resilience: "specified resilience" which answers to the question 'what' needs to withstand 'what', and "general resilience" a broad-based capacity to deal with any surprise or disruption (Carpenter et al., 2001; Folke et al., 2010; Resilience Alliance, 2010). Both specified and general resilience are important, as they offer complimentary, though sometimes contrary benefits (Folke et al., 2010).

Several top down approaches are available to increase specified resilience in complex systems. These include initiatives such as investments in hardening infrastructure, in applying "defence-in-depth" engineering standards, and investments in good practice methods such as risk management, business continuity management, and disaster management (Van der Merwe et al., 2018a). Approaches to cultivating general resilience, on the other hand, deploy techniques based on complexity thinking – recognising that resilience is an emergent systems-level outcome that tends to be intangible, dynamic, and not readily quantifiable. Because it cannot be produced directly, bottom-up approaches are best suited (Van der Merwe et al., 2018a).

This paper reports on resilience thinking applied to the electricity sector in South Africa, in Eskom the national electrical utility. Initially the programme focussed on specified resilience. Gradually the focus is shifting to incorporate the cultivation of enabling conditions for general resilience to emerge.

The ART of resilience
Eskom has a strategic objective to be risk-intelligent and resilient. In support of this, the resilience team simplified its communication of desired resilience capacities by introducing the concepts of the ART of resilience. This convey the idea that resilience is more than the ability the ability to "bounce back", and avoid more abstract definitions that make it difficult for frontline staff to engage with in their day-to-day work. The *"ART of resilience"* functions as a heuristic for the ability to *"anticipate and adapt, respond and recover, and transform".* It complements memes such as *"system steward"* and

"storm role" that have been introduced by the team to probe how a sense of social identity might play a role in three kinds of networks that contribute to the cultivation of resilience in organisations, namely formal day-to-day structures, emergency response structures, and informal networks (R. G. Koch, 2020). The metaphor of "art" is seldom about the application of rules and more often about working with the affordance of the context in the moment (R. L. Koch, 2020).

Anticipate & Adapt: The ability to anticipate opportunities or threats, and adapt "in time to matter" enhances the capacity of an organisation to survive and thrive in dynamic change (Lee et al., 2013). It requires responding to patterns/trends not distinctly visible, which is challenging in organisations that prefer stability and resist change. Systemic change levers at these depths include altering material flows and changing process feedbacks, supported by double loop learning (Flood & Romm, 2018; Meadows, 1999). Adaptive capacity is the hallmark of resilient systems and can be fostered in organisations by adaptive leaders (Folke et al., 2002; Hollnagel, 2012; Uhl-Bien & Marion, 2009).

Respond & Recover: The ability to respond and recover to a pre-disturbance state is promoted through establishment of response plans from different disciplinary perspectives (emergency preparedness, crisis, business continuity and disaster management), and structures and processes for incident coordination at various levels (site, provincial, divisional and national plans). The visibility of business-unusual incidents supports the mobilisation of response action. Responses to and recovery from sudden-onset incidents are typically urgent, fast-paced and relatively short cycles to allow the organisation to return to business-as-usual. However, it can also be protracted, as in the case of drought or the global pandemic. Emergency response takes place locally at the coal face, even though the need to respond may be widely distributed. Operational leadership are well positioned to instil response and recovery capacities in organisations (Van der Merwe et al., 2018a).

Transform: A system transforms when there is a change in the trajectory of its growth path (Folke et al., 2010). Although regime shifts can force rapid transformation, the capacity to bring about intentional transformation requires strategic leadership leading to societal effects (Van der Merwe et al., 2018a). The transform cycle is slow and disruptive and corresponds with the panarchy (Allen et al., 2014; Gunderson & Holling, 2002). It is imperative for the electricity industry to transform from fossil fuels towards renewables in a manner that does not leave coal-dependent communities behind, referred to as a just energy transition. Systemic change levers at this depth include changing the vision of a system and shifting paradigms, supported by triple loop learning (Flood & Romm, 2018; Meadows, 1999). An essential catalyst of transformational change is an internal and tacit quality of leadership consciousness described as wholehearted courage, compassion, connection, and vulnerability, after O'Brien *"The success of an intervention depends on the interior condition of the intervener"* (Senge & Scharmer, 2008; The Mandela Rhodes Foundation, 2018).

Cultivating the ART of resilience

The Resilience Team engages in multiple "safe-to-fail" experiments to cultivate the ART of resilience across the organisation (Holling, 2001). These approaches use narrative and dialogue to understand and affect change in organisational sense-making, collective action and meaning-making. The aim is to seed bottom-up emergence towards more desirable resilience futures. Examples include:

a) **Formative resilience assessments**: Assessments can be distinguished as summative or formative, where summative assessments are performed top-down "of" resilience for reporting of established capacities or for comparison, while formative assessments are performed bottom-up "for" resilience to shape intrinsic thinking, to monitor progress and inform new interventions to enhance capacities agreed upon (Van der Merwe et al., 2018a). Formative resilience assessments consist of ongoing conversations among actors in a system about what is, what should be, and how to achieve agreed upon priorities. Such social innovation processes increase buy-in and intrinsic motivation to affect change (Westley et al., 2011). Formative resilience assessments contribute resilience thinking, adaptive capacity and collective action in a system (Van der Merwe et al., 2018b).

   Formative interventions are designed as short, repeatable probes to engage with the social fabric of the organisation. Participants draw inspiration from nature-based resilience building principles - and apply it to aspects of the ART of resilience to design small collective interventions to strengthen resilience in the organisation. Generic resilience principles used in the process address what is to be managed in a complex adaptive system, how to think about the system, and how to govern the system for resilience (Biggs et al., 2015). The facilitation is employ appreciative inquiry as it emphasise participation, leads to collective action, increase resilience and supports transformation (Cojocaru, 2014; Holman, 2010; McArthur-Blair & Cockell, 2018). Holman (2010) describe appreciative inquiry as a systemic change approach to deliberately engages emergence. Interventions started in 2017, and are online since March 2020. Anecdotal evidence suggests changes in participant behaviour and mind-sets and increased levels of intrinsic motivation to affect change personally and professionally. Some participants return, others arrange interventions for their teams. Recently participants volunteered to take these interventions to their divisions or places of work to systematically explore *"how Resilience can be used to address issues."* In the words of a participant *"Please continue to challenge and assist our management at different levels to transform and we will do our bit to do it in our areas of influence."*

b) **Shifting narratives in the organisation**: Another approach used to influence conversations (micro-narratives) in the organisation is the hosting of internal events where employees who were groomed to deliver TEDx-styled talks share something they are passionate about that illustrates resilience and innovation. This process is extending to sessions dedicated to stated organisational values (such as innovation) to address the context the organisation is in.

c) **Connecting networks of communities**: Managing connectivity is one of the resilience thinking principles deployed to enhance collaboration between practitioners in the risk management and resilience communities in the organisations. Risk Management perform a three-yearly audit to verify compliance to the risk management standard. Recognising that a probe is also intervention this opportunity was used to inject an exploratory assessment of emerging ideas – beyond the "rules" in the standard - to improve the integration between risk and resilience. This probe into the risk management community's levels of awareness about resilience was used as a bridge between these communities.

d) **Fostering collective social identity**: Traditional organisational structures were designed around predefined roles – based on the metaphor that an organisation is a "well-oiled machine" (Allen et al., 2011). Resilience practitioner need to understand the importance of "cultivating" informal networks, an intentional emphasis on an alternative metaphor of the organisation as an ecology (Allen et al., 2011). An approach to social identity has been adopted using concepts of "system stewards" and "storm roles" to nurture beneficial conversations in the ecosystem.

An underlying principle, discussed in a parallel paper, is to promote a collective sense of coherence across the organisation - by assisting people to make better sense of change and disruption, and to strengthen connectedness, agency and meaning across the system.

Conclusion

Top-down approaches to building specified resilience are valuable and necessary, but may be inadequate to contingent situations which exceed planning assumptions (Bakken & Hernes, 2010). General resilience offers the emergent capacity to adapt and transform across multiple equilibria in the face of uncertainty, unforeseen risks, and unknowable surprises (Caldwell, 2014; Folke et al., 2010; Van der Merwe, 2019). General resilience cannot be produced directly; it requires complexity thinking, bottom-up processes, and emergent practice to catalyse the emergence of resilience in a system. The ability to infuse adaptive and transformative capacities into complex adaptive systems requires an ongoing emergent engagement with deep systemic change levers and internal leadership consciousness that embrace courage, compassion, connection, and vulnerability (Holman, 2010; Meadows, 1999; The Mandela Rhodes Foundation, 2018).

This paper illustrates bottom-up safe-to-fail experiments explored to stimulate the emergence of resilience at multiple levels across a large essential service organisation. These approaches use narratives and participative dialogue, as well as formative resilience assessments to cultivate resilience capacity. These bottom-up approaches contribute to the ability to engage in the *ART of resilience* – i.e. the ability to: *"anticipate and adapt to change; respond to surprise and recover from disruption; and to transform in light of significant shifts in context".*

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D. Governance systems and institutional arrangements for STE resilience
D.s14. Top down or Bottom Up? Planning approaches and Collective Action for Resilience

Using sense of coherence to cultivate enabling conditions for social resilience

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Summary
System stewards are seeking bottom-up approaches to foster informal institutions to enhance resilience in socio-technical-environmental systems in order to adaptively navigate the intractable challenges society face.

This paper discusses an approach to foster enabling conditions for resilience to emerge to predispose an essential service organisation towards general social resilience in support of resilient services delivery. The approach is based on collective sense of coherence, which is a predictor of general social resilience across scale. Someone with a high sense of coherence have a general tendency to conclude that the world is (i) comprehensible, (ii) that challenges are manageable, and (iii) meaningful to engage in (Antonovsky, 1987a). SOC can inform meso-level interventions on the institutional framework in an essential service organisation to enhance resilient service delivery.

Keywords
Resilience of complex adaptive socio-technical system; sense of coherence; meso-level intervention; informal institutions

Introduction
Society benefits from the service delivered by socio-technical-environmental systems. For example, ecosystem services, like pollination and soil regeneration sustain life, health and human well-being, while essential services, like water, electricity, and connectivity, sustain the modern way of life (Auerswald et al., 2006; Biggs et al., 2015). Resilience is an emergent outcome from complex adaptive systems and cannot be produced directly (Van der Merwe, 2019). Understanding how to increase the resilience of these complex adaptive systems is important. There is particular interest into enabling conditions that may predispose a STE system to resilient service delivery.

The context of this work is Eskom, the national state owned power utility in South Africa, which generate 90% of the electricity consumed in South Africa (Eskom, 2020). This essential service system is deeply entangled in technical, social, economic, environmental, and political aspects (Baker & Burton, 2017; Jaglin & Dubresson, 2016). Amidst chronic and acute challenges, the Eskom Resilience Team employs ambidextrous resilience building strategies and explores ways to adaptively strengthen general resilience.

This paper use collective sense of coherence (SOC) to inform social intervention strategies and enhance the social system's propensity/tendency towards general social resilience. People with a healthy SOC have a general orientation to conclude that the world is comprehensible, that challenges are manageable, and that it is meaningful for them to engage in these challenges (Antonovsky, 1998). Levels of SOC are influenced by general resistance resources or deficits during upbringing and is open to intervention (Idan et al., 2016; Mayer & Boness, 2011). This paper proposes meso-level interventions to improve collective sensemaking, collective meaning-making, agency and connectedness among employees charged with essential service delivery and emergency response to large incidents. Meso-level interventions shape the ecosystem in which organisations operate through institutional change (Cunningham & Jenal, 2016; Esser et al., 1996). In turn, institutions structure human interactions through formal rules and informal norms (North, 1991). This paper draws on literature with similar themes supplemented by practical ways practitioners can act in the system to stimulate collective SOC.

Collective Sense of Coherence (SOC)
How people make sense of the world determines how they act (McDaniel & Driebe, 2005). Effective sense-making informs effective response and is critical for resilience (Casto, 2014; Dekker et al., 2008). Unfortunately sense-making can fail, and this momentary inability to cope with complexity can lead to disaster (Casto, 2014; Dekker et al., 2008; Weick, 1993). SOC is a general predictor of

psychosocial resilience and of effective sense-making (Lindström & Eriksson, 2006; Van der Merwe et al., 2019).

SOC provide people with a general tendency to (i) make sense cognitively of unfamiliar situations; (ii) make sense instrumentally of how to access the resources required to cope and manage; and (iii) make sense emotionally of their motivation to act with meaning and purpose (Van der Merwe et al., 2019) (refer to Table 1). People with healthy levels of SOC has the propensity to cope with stress and act amidst challenges (Van der Merwe et al., 2019). Social groups with lower levels of SOC experience more fear, anxiety, and depression (Kimhi et al., 2020). SOC reflects an enduring general orientation to life and is a multi-level concept across temporal, spatial and organisational scales, applicable to individuals, families, communities, organisations and nations (Braun-Lewensohn, 2014; Braun-Lewensohn & Sagy, 2011; Eriksson & Lindström, 2005; Idan et al., 2016).

Table 1: Dimensions of Sense of Coherence

Comprehensibility	**Manageability**	**Meaningfulness**
Cognitive dimension	Instrumental dimension	Emotional dimension
People see the world as comprehensible if they conclude they understand what is happening around them (Harrop et al., 2006).	People perceive that the resources required to deal with the demands posed by the world are available through their social connectedness (Harrop et al., 2006).	People see challenges as meaningful if they have the motivation to invest time and effort into it (Bonacchi et al., 2012; Harrop et al., 2006). Meaningfulness/purpose is the strongest contributor to resilience.

Multi-disciplinary perspectives on Sense of Coherence

Antonovsky was a medical sociologist and formulated SOC after years of research among Holocaust survivors, and a realisation that researchers should not study the origin and progression of disease, but of health and strength instead (Antonovsky, 1979). SOC literature describe comprehensibility, manageability and meaningfulness (Antonovsky, 1987; Bauer & Jenny, 2016; Eriksson & Lindström, 2005; Harrop et al., 2006). We explore approaches to operationalise collective SOC from literature with the same three themes. Table 2 below provides a synthesis across these disciplinary perspectives that may inform approaches to build collective SOC.

Public Management aims to build community resilience, yet researchers found gaming of outcome-based performance management leads to unintended consequences detrimental to systems health (Knight et al., 2017; Lowe & Wilson, 2015). Investigations into Public Service practices in healthy systems noted the presence of people who identify themselves as systems stewards, namely people who look out for the health of the system (Lowe & Plimmer, 2019). Among other things, system stewards help others understand the system by (i) making the system visible, (ii) building relationships and trust, and (iii) establishing shared purpose.

Pedagogy research on dropout rates shows that (i) cognitive competencies are not enough to graduate from tertiary education. They concluded that (ii) interpersonal and (iii) intrapersonal competencies are essential for holistic student resilience (National Academies of Sciences Engineering and Medicine, 2017; Noonan & Gaumer Erickson, 2017). The University of Kansas developed a framework of required skills (Research Collaboration, n.d.). Examples in Table 2.

The Resilience Shift explores critical infrastructure resilience and sought to extract real-time leadership lessons from the crisis brought about by the global pandemic. They distilled insights from interviews with senior resilience leaders conducted every week for 16 weeks. They concluded there are three areas leaders need to attend to during a crisis: (i) a technical dimension, (ii) a societal dimension with strategies to lead people and society, and (iii) a personal dimension pertaining to internal leadership qualities (Willis & Nadkarny, 2020). Examples are listed in Table 2.

Table 2: A multi-disciplinary synthesis on how to promote collective Sense of Coherence

	Comprehensibility	**Manageability**	**Meaningfulness**
Role of change agents	System stewards contribute to sense-making in the system by making the system visible and this help people to see the world as comprehensible.	System stewards contribute to network weaving in the system by building relationships and trust and this helps people to see the challenges in the world as manageable.	System stewards contribute to meaning-making in the system by establishing shared purpose and this helps people to see their role in the world as meaningful.

	Comprehensibility	Manageability	Meaningfulness
Skills to develop	Develop cognitive competencies, e.g. creative thinking, problem solving, and organization. Prepare leaders to perform technical leadership strategies under pressure, e.g. to understand and monitor a crisis, maintain operational functionality, and manage cash.	Develop interpersonal competencies e.g. teamwork, networking, and conflict management. Mentor leaders in strategies to lead people and society under pressure, e.g. to demonstrate care, build and sustain trust, and contain anxiety.	Develop intrapersonal competencies e.g. a growth mind-set, self-regulation, and tenacity. Cultivate internal leadership qualities required under pressure, e.g. to be calm, reflect and learn as you go, assume authority, and then delegate it where it can do most good.

These ideas point to ways of thinking and acting to enhance collective SOC in a system.

Strategies to build collective Sense of Coherence in Eskom

The Enterprise Resilience team has adopted collective SOC as an approach to intervene in systems-level sensemaking and meaning-making for collective action across the electricity supply system. They see themselves as system stewards who act in the system with ambidexterity. How they do what they do is vital. What they do is top-down deployment of good practise, but how they do it is being consciously mindful of promoting collective SOC in the process. Practical ideas, summarised in Table 3, pertain to establishing preparedness, performing emergency response and extracting organisational learning from experience.

Table 3: Practical approaches to promote collective Sense of Coherence in the organisation

	Comprehensibility	Manageability	Meaningfulness
Preparedness	• Employ participatory planning processes to compile business continuity and disaster plans • Identify a range of storm roles (also beyond explicit operational response roles) and make dependencies between roles and ICS structures explicit. • Appoint people into storm roles and expose them regularly to simulation exercises which include introspection on the sensemaking that happens. • Collectively determine response principles as guiding heuristics during response. • Foster shared mental models to enhance understanding of big picture.	• Strengthen social capital and social network connectivity for flow of information, resources and ideas across the network. • Clarify how information and resources flow in the Incident Command System (ICS). • Emphasise agency that individuals have / should develop in responding within the necessary governance constraints.	• Empower people with agency to act. • Clarify the purpose of storm roles in contributing to the overall response. • Foster commitment to a common purpose – considering multiple factors (including the safety of the society served, the safety and health of colleagues etc.). • Show the integrated nature of the power system for supporting services to recognise their contribution to operations.
Response	• Verbalise guiding heuristics. • Update situational awareness relative to shared mental models. • Acknowledge authority of storm roles.	• Focus integration conversations around ICS. • Draw on established networks to access resources required to cope.	• Acknowledge people involved in the heat of the action. • Remind those removed from operations of the contribution of their role to restoration.
Learning	• Review aspects of response that worked / failed during incidents to extract learning and update guiding heuristics. • Explicitly visualise and review shared mental models to grow mutual understanding.	• Evaluate sufficiency of flow in support of response, strengthen connections, formalise new connections that emerged from actual incident.	• Following an incident issue a leadership communique to thank participants for their contribution to the response & highlight how their effort supported the needs of external stakeholders.

Empirical results reveal high levels of meaningfulness and low manageability in Eskom. Connectedness translates into manageability as levels of connectivity, trust and social capital in social networks enable information, resources and ideas to flow to where context demands. Systems with high levels of internal connectedness exhibits more control over its destiny (Holling, 2001).

The general culture of an organisation can enable or constrain resilience. A reductionist view of organisation and a Tayloristic approach to management may stifle resilience and affect collective SOC, even if employees have high levels of individual SOC in their personal capacity (Van der Merwe et al., 2019; Woltjer et al., 2015). Enabling informal institutions are essential to permit collective action for resilience (Van der Merwe et al., 2019).

Conclusion

SOC reflects a general psychosocial tendency to survive and thrive amidst stressors. Collectively it reflects a quality of sense-making, connectedness, agency and meaning among people, which highlights the contribution of social considerations on resilience. SOC offers coping capacity and is an incentive to act amidst difficulty and disruption (Almedom et al., 2007; Eriksson, 2016; Van der Merwe et al., 2019).

Collective SOC may be seen as an emergent systems-level outcome, and offers system stewards meso-level approaches to influence informal institutions in an organisation to cultivate collective action for resilience. Although SOC provide general resistance resources in the face of stressor and challenges, it is not clear if it offers society adaptive and transformative capacities to deal with systemic problems. More work is required to explore meso-level interventions to enhance the system's propensity for collective SOC, as well as to confirm whether SOC enable adaptive and transformative capacity to deal with deeper systemic challenges.

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The concept of community resilience explored: How to account for responsibilities?

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Summary
Resilience is often said to involve new responsibility arrangements between state and local actors. However, the literature on resilience has hitherto devoted limited attention to the responsibilities that citizens are expected to assume under different resilience regimes. In this paper, we develop a normative notion of resilience that allows for a more transparently normative analysis of community resilience. The template thereby developed provides a first tool to think about the citizen responsibilities in a more formalized way.

Keywords
community; ethics; normativity; responsibility; systems thinking

Introduction
Resilience is often said to involve new responsibility arrangements between state and local actors, with an increasing emphasis on the responsibilities of citizens (Butler and Pidgeon 2011). However, the literature on resilience has hitherto devoted limited attention to the responsibilities that citizens are expected to assume under different resilience regimes (Hegger et al. 2017). In this paper, we will develop a normative notion of resilience that can account for the responsibilities of different actors in realizing resilience.

Different framings of resilience
Although the term resilience is in itself not new – its early use dates back to the 18th century when it was used to denote the strength of materials (McAslan 2010) – the contemporary use of the term resilience as a concept that typically applies to *systems* rather than *isolated components* originates from discussions in system dynamics and ecology in the 1960s (Holling 1973). Crucial for systems thinking is that the performance of a complex system is more than the performance of the parts or components that make up the system. After its introduction into ecology in the 1960s and 1970s, the term resilience became popular in other domains as well. With this, also the social dimensions have begun to be integrated in resilience thinking (Adger et al. 2009).

In the literature, two dominant frames of urban resilience have emerged, emphasizing different characteristics of the resilience of urban communities (Wardekker forthcoming). The first is a “system framing” of resilience, which emphasizes its roots in system dynamics and which is also the most common policy discourse. Many approaches to urban resilience are consequently also rooted in this literature (e.g., Biggs et al. 2015). Urban resilience is, e.g. “the ability of the city to maintain the functions that support the well-being of its citizens” (Da Silva et al. 2012), conceptualizing cities as systems with components, functions, and flows of, among other things, resources, materials, and people (e.g. Meerow et al. 2016).

The second is a “community framing” of urban resilience, which has its roots in disaster preparedness and psychology and which focuses on how communities are impacted by disturbances (Norris et al. 2008). Local citizens and other small stakeholders are the key players in this framing of urban resilience, emphasizing urban life, community bonds, and self-sufficiency. Typical resilience principles are derived from social science literatures, such as social networks, leadership, engagement, information flow, learning, societal partnerships, societal equity (e.g., Berkes and Ross 2013).

Both sub-literatures on urban resilience have hitherto devoted limited attention to the responsibilities that private actors are expected to assume under different resilience regimes and how this should be complemented with public actors’ responsibilities. The system frame focuses primarily on the role of infrastructures and not individual citizens. The community frame pays little attention to the interaction between citizens and actors beyond attending to the community itself.

Resilience as a normative notion
In order to develop a normative notion of resilience that can account for responsibilities, let us explore the different elements in a template of resilience based on how the term is used in different disciplines. The most basic definition of resilience defines resilience as the ability of a system to maintain its functions after disturbance (Walker et al. 2004). This could be written in the form of a template:

Resilience^1 := the ability of system S to maintain its functions F after disturbance D.

The elements in this template and the schematic letters used for them are as follows:
S: the entity (system) to which the label resilience applies.
F: the functions which the system should be able to fulfil in order to count as resilient.

A second, more advanced, description of resilience provided by Folke (2006) adds the element of self-organization and here the emergent character becomes more important. While self-organization is a difficult concept to formalize, at the minimum it pre-supposes that there are elements within the system that somehow relate to the overall functioning of the system. In a social context, that would mean that the elements that constitute the system should be able to deliver to the functions of the system. A richer formalization of resilience therefore reads:

Resilience^2 := the ability of system S to maintain its functions F through the actions A of its components C after disturbance D.

The last description provided by Folke (2006) defines resilience as the ability to learn and adapt. In this resilience engineering paradigm, a resilient system is a system that is able to show successful behavior in a changing environment, where this changing environment is not necessarily conceived of as one of threats, but rather one of change and surprises (Doorn 2021). One way to formalize this is by generalizing the 'disturbance D' of Resilience^2 to the more open 'changing situations'. Also the preposition 'after' suggests that resilience is limited to reactive recovery after some disturbance. A more general formulation that allows for learning and adaptation would therefore read as follows:

Resilience^3 := the ability of system S to maintain its functions F through the actions A of its components C in changing situations Sc.

Let us now see how we can give substantive to the different letters in Resilience^3. First the system S to which the label applies, this is usually a specific community. It can be a localized community but this is not necessarily so. In case of climate adaptation, the community will often be a localized one, for example a neighborhood or a city, but in relation to other threats the community may be much more dispersed geographically (cf. terrorism, virtual threats, migration). The exact demarcation, however, is far from trivial.

From an ethics point of view, a crucial next step is to give substance to the functions F and the components C. Let us start with the components C. Since our quest concerns human systems, we suggest to take humans as the primary components of the system. True, the people who together constitute the community may need resources and infrastructure, but in this normative notion of resilience, people make up the components who act. Other components of these socio-technical systems can be considered supporting resources.

The functions F that a community should be able to fulfil is again clearly a normative question. At the most basic level, the functions that a community fulfils vis-a-vis its members is inextricably linked to the question of what a good society is. Candidate for functions here are: providing a safe, secure, and/or livable place for humans to live in. What the exact function is, is context-dependent, but it should probably at least provide a place where people's basic rights are respected. In the scarce literature on resilience ethics specifically devoted to issues of justice, the capability approach has been suggested as a normative theory to give substance to the 'functions' that a society should be able to fulfil (Doorn 2019).

Sc stands for the changing situations. The term ‘changing situations’ allows for some specification without the need to define what the exact changes are. However, if resilience is to make an impact on policy making, it is of course necessary to provide the relevant context, for example whether resilience is discussed in the context of, say, climate change or an aging society.

The actions A, lastly, allow for the inclusion of responsibilities. But a question remains: Do the actions refer to coincidental acts performed by people or to specific tasks or obligations? To conceive of these actions as specific, maybe even pre-defined obligations or responsibilities seems to go against the emergent character of resilience. This suggests that the use of the term resilience should maybe not be taken too literally but rather be seen as a metaphor for how society can deal with changing situations. Instead of talking about responsibilities, it may sometimes be more effective to focus on the conditions that make the desired emergent behavior likely rather than focusing on the responsibilities of citizens themselves.

Conclusion

In this paper, we thus develop a formal template that allows for a normative analysis of community resilience. The elements in the template are not intended as a blueprint for what it is to make something resilient. Rather, they should be seen as elements to consider when assessing the resilience of some community from an ethics point of view. This prompts the question how close a normative notion of resilience for communities should stay to the original idea of ecosystem resilience. The template developed above sketches a tentative approach to think about these responsibilities in a more formalized way.

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Governance systems and institutional arrangements for STE resilience
Governing Systemic Risks with Morally Sensitive Resilience Strategies

The Normativity of Resilience

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Summary
This presentation asks whether resilience is a normative term, and answers this question in the affirmative. I start by explaining two arguments that have been offered in favour of the 'resilience-as-descriptive' thesis (RD). Then I criticize this view by advancing five reasons why resilience should be considered a normative term (RN).

Keywords
Resilience; normativity; metaethics; instrumental values; normality.

1. Introduction

While there is much disagreement among scholars and practitioners on whether resilience is a desirable goal, and to what extent, an emerging consensus seems to be that resilience-is-normative (RN), meaning that it provides new orientations for acting in various kinds of complex systems (Pelling 2010; Walker et al. 2011; Joseph 2013; Meerow et al. 2016; Kolers 2016). Yet, interestingly, authors linked to the Resilience Alliance have rejected this view to hold the opposite thesis: that resilience-is-descriptive (RD). Here I discuss the normativity of resilience by engaging resilience research and metaethics, the area of philosophy most directly concerned with normativity. I start by presenting the two main arguments advanced in favour of RD. Then I turn to offering five reasons in support of the alternative view, that resilience is normative (RN).

2. Resilience-is-descriptive (RD): pro-arguments

The Resilience Alliance seems 'officially' committed to the view that resilience is descriptive or non-normative (Carpenter et al. 2001; Holling & Walker 2003; Walker et al. 2004; Brandt & Jax 2007; Anderies et al. 2013; Thorén & Olsson 2017; Elmqvist et al. 2019). Two arguments have been offered in support of this view, each of which implies one distinct criterion for ascribing normativity.

1. A normative concept must entail "specific choices about performance measures". Yet, resilience cannot be a goal or convey prescriptions, because it is not a precise concept. So, etc. (Anderies et al. 2013).
2. A normative concept cannot be ambivalent: it must **either** imply something positive (desirable), **or** negative (undesirable), in the following way.
   - (i) **intrinsically**, e.g. good as an end/as such, as opposed to "good as X", "good for X", etc.: for example, dictatorships are undesirable as such, and sustainability is desirable as such; whether resilience is desirable depends on the system in question.
   - (ii) **consistently**: it is desirable OR undesirable, always and under any circumstance. Resilience can be desirable or undesirable: poverty traps and rigidity traps are, by definition, very resilient, and there exist both resilient democracies and resilient dictatorships.
   - (iii) **exhaustively**: captures everything good/bad: e.g. something sustainable cannot be bad in some way. Resilience is "distinct from sustainability [in that we] seldom hear of sustainable dictatorships, but there are resilient dictatorships." (Anderies et al. 2013, 5).

   Resilience is ambivalent, and so it is not normative.

Given these considerations, for example, Derissen et al. (2011) claim that sustainability is a moral (normative) concept, while resilience, in contrast, is a complex systems theory concept, or an ecological concept. One consequence of this view of resilience is that, although managers and policy-makers need to take resilience into account, resilience cannot be a design or management goal. Sometimes we might want to improve resilience, but, if the system is in an undesirable state, we want to fight resilience and ultimately erode it. In other words, we should not "manage for resilience", but "manage resilience". For example:

> "Governance for sustainability will require active management of resilience by either reducing or strengthening resilience" (Elmqvist et al. 2019, 5).

This view does not deny that managing resilience involves making normative choices. This is unavoidable in operations such as selecting a system, a social theory, a disturbance of interest or a critical property to maintain after disturbance (Brandt & Jax 2007; Thorén & Olsson 2017). However, normativity is not implied by resilience per se, but in applying resilience as part of management or design interventions.

3. Criteria pro-RD are not metaethically sound

One reason why RD is wrong is that the two arguments pro-RD are not metaethically tenable.

1. This criterion is absurdly wrong. If resilience was not normative for this reason, then concepts like "good" or "justice" could not be normative either.
2. The three requirements are wrong (sufficient but not necessary).

(i, ii). **Counterexample: efficiency.** Consider the intrinsic/instrumental distinction. **Intrinsic values** (goods) are ends that are desirable for themselves: **e.g. equality** is an intrinsic value regarding wealth distribution. **Instrumental values** (goods), in contrast, do not qualify ends, but only means or processes by which other ends are attained. These values are desirable insofar as they warrant, or enhance, the satisfaction of intrinsic values, but can also be undesirable if put to ill-chosen ends (van de Poel 2018): **e.g. efficiency.** Sharing riches efficiently improves equality, which makes efficiency instrumental to equality. But efficiency aggravates outcomes when it serves wrong ends, e.g. efficient killing machines are worse than regular killers. **Conclusion:** *efficiency is not consistently or intrinsically (un)desirable. Still, it remains a value, and so a normative concept. Something similar applies to resilience.*

(iii). **Counterexample: Cuba is a sustainable dictatorship.** Sustainability concerns distributive justice within and across generations, i.e. justice in the allocation of goods. In the last decade, Cuba featured as **one of the countries with the highest rates in human development (HDI) for an acceptable ecological footprint** (EF) (Cabello et al. 2012; Niccolucci et al. 2012). Still, Cuba does not grant equal opportunity of access to political office (Rawls 1999): it is **procedurally unjust (and a dictatorship)**. But that does not make sustainability any less normative. Sustainability just cannot capture everything good: sustainable regimes can still be unjust. **Conclusion**: *a concept can be worth realizing and still not capture some desirable things; in other words, desirable ends/values can still carry value tradeoffs.*

4. Some resilience concepts are clearly normative

The articles that see resilience as descriptive, or non-normative, tend to think of resilience as monosemic, and to frame it as a close surrogate of **LOCK-IN (table 1):**

> **Lock-In:** "state where path-dependent and **positive feedback processes create and reinforce systemic barriers to alternative pathways**" (Unruh 2000).

Another objection against RD, then, is that it pushes for a peculiar and idiosyncratic concept of resilience, whereas resilience is polysemic (it designates at least various distinguishable concepts), and some of the concepts it designates are clearly normative. For example, adaptation research is influenced by psychology and community psychology research, and, here, resilience definitions stress the positive character of adaptation and/or recovery **(table 1).** Also, in his 1978 monograph on Adaptive Management, Holling holds that resilient systems do not merely persist. In addition, when decline is inevitable, they can decline gracefully, and besides they are opportunistic: they can use change to become better. In other words, resilience can be a surrogate of **ANTI-FRAGILITY**:

Anti-Fragility: "property of systems that **benefit from shocks** and that thrive and grow when exposed to volatility, randomness, disorder, and stressors" (adapted from Taleb 2012).

5. Resilience is linked to various classes of thick terms

Thin terms are terms that only have normative content. Example: paradigmatic normative terms like *good, right, should,* etc. Thick terms, in contrast, have *descriptive* as well as *normative* content. Table 2, below, contains some examples of thick terms, divided in classes. This is a sample: there are many more classes.

Philosophers have discussed a variety of criteria for assessing whether an allegedly thick term is normative. RD has been defended (2^{nd} argument) with:

- **Consistency (ConC):** a term is thick *iff* it consistently implies a positive (negative) valence. Examples: *cruel, painful, happy.* **Sufficient, not necessary.**

However, there are two other criteria:

- **Separability (SC):** a term is thick *iff* we can disentangle its normative and descriptive aspects. e.g.: *murder* is "*wrongful* deliberate killing"*, knowledge* is "*justified* true belief". **Sufficient, not necessary.**
- **Membership (MC):** a term is thick iff it meets the criteria for being considered a member of a class of terms that are widely regarded as thick. **Sufficient…necessary?**

By using the separability criterion (SC) and the membership criterion (MC), resilience can be linked to various classes of thick terms, and so, qualified as normative.

- **Minimally, resilience is an instrumental value**. "Lock-in" resilience is closely linked with **efficiency** or **robustness**. As is already implicit in 2^{nd} argument pro-RD: poverty traps, rigidity traps make resilience undesirable, but applied to other ends or patterned states (e.g. virtuous cycles), resilience is desirable.
- **Moreover, resilience is plausibly a virtue.** Virtue terms like e.g. **generosity** express (Battaly 2015):

  (1) acquired character traits (in social terms: learned, not transcultural) – MERIT

  (2) that involve performing RIGHT actions;

  (3) that (tend to) produce GOOD OUTCOMES;

  (4) and that involve GOOD MOTIVES.

  At least some resilience concepts pass this test (e.g. adaptation, anti-fragility). In fact, resilience is **often seen as a virtue:** an ability that persons and/or organizations would like to have and/or promote.
- **Resilience is closely linked with achievement verbs.** These verbs imply success and/or conduct appropriately oriented to certain ends: success therefore carries merit, and one deserves credit for it: e.g. **to know** is to be successful in being true and appropriately justified; one is owed some credit for knowing. Similarly, being resilient denotes that one persists **due to** some peculiar traits and merits. This classification is indisputable when we talk about resilience in human contexts.

6. Resilience is a naturalness/normality concept

Concepts implying a "relation of conformity to norms" (e.g. normality, obsolete, deviant, disturbance, critical, naturalness, etc.) broaden established views on normativity. They are not prescriptive (e.g. *must, justified, right, permissible*) in the sense of directly expressing an obligation; nor are they evaluative (e.g. *praiseworthy, admirable, bad),* in the sense of conveying positive, critical or negative appreciations. But Wittgenstein once claimed that we do many things that cannot be justified except by appeal to "what we normally do in such circumstance", that is, by appeal to conformity to norms and expectations, or deviation from them (Eldridge 1986). Resilience denotes maintaining or returning to standards, or developing new ones, and so is normative in this way (VI).

Tables and figures

Table 1. Resilience concepts

Concept	Source	Definition	Change of trajectory
LOCK-IN	Elmqvist et al. 2019	"Capacity… to absorb disturbance, **reorganize**, maintain essentially the same functions and feedbacks over time and **continue to develop along a particular trajectory**."	No (+graceful decline)
ADAPTATION	Norris 2008	Ability to show a positive trajectory of functioning and adaptation after an initial disturbance, [as the] result of adequate adaptive capacities	Yes, positive
ANTI-FRAGILITY	Holling 1978	"[Ability] to absorb and **utilize (or even benefit from)** change."	Yes, positive (+ graceful decline)

Table 2. Classes of thick terms

	Type/domain of application	Examples
THICK →	Paradigmatic	*Good/bad, beautiful/ugly*
	Values	*Freedom, love, autonomy, health, self-respect, **efficiency, robustness***
	Achievement verbs	***Know**, learn, produce, understand*
	Virtues/vices	*Courageous, **generous**; foolhardy, arrogant, stupid*
	Political/economic/religious	*Utility, progress, sustainable development, God, sacred, democracy*

Conclusion: other morally problematic aspects of RD?

<u>Incongruence with resilience thinking?</u> The Resilience Alliance often stresses the progressive potential of resilience thinking: e.g. by criticizing rigid distinctions between society/culture and nature, by speaking of socio-ecological systems, by denying that humans can set themselves goals independently of nature, etc. It seems incongruent, then, that they commit to a descriptive/normative dichotomy (which validates those 'old' distinctions they criticize), and further, that they push for RD. Here I have argued that resilience is best seen as a descriptive and normative term (a thick term).

<u>Disciplinary imperialism?</u> Further, it is crucial to first decide which resilience concept we are going to use: for example, the RA insistent push for a lock-in concept could be considered an exercise of academic imperialism (e.g. it disregards the psychology concept).

<u>Positivistic and depoliticizing?</u> One way of interpreting the effects of modern science is that it politicized many aspects of the world by naturalizing what religion had previously thought supernatural (and thus, depoliticized). However, science can be depoliticizing: positivistic ideology consists in naturalizing problems that are social or have a social dimension; likewise, neoliberal economic ideology naturalizes economic injustice, not just by idealizing market competition but, more precisely, by identifying society with a (distorted) view of nature as "red in tooth and claw", whereby market competition is natural, and therefore good. My arguments demonstrate that it is at least very plausible that resilience has embedded values, and so, the RD view would obscure these values and hide them from public discussion. I think that this constitutes a form of positivistic ideology that could have a depoliticizing effect on policies and agendas of resilience building.

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[Special Session: Governing Systemic Risks with Morally Sensitive Resilience Strategies]

Integrating fairness into adaptive governance: developing a contextual approach of fairness

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Summary
The renewal and re-organisation inherent to resilient systems has inevitably an important normative layer, but this is often overlooked in the literature. There seem to be two main strategies: either one can apply theories of justice to the case at hand or one can organise a participation and deliberation process about it, but both strategies have important limitations. Therefore, this papers proposes a position in between both, namely a contextual account of fairness, which aims for an equilibrium between local community standards of fairness and universal justice principles. This is illustrated by applying this approach to the case of electricity network tariffs. We show how an integrated fairness assessment can look like, based on combined insights from economics, behavioural sciences and ethics. At the end of the paper, we discuss next steps for the developing such an integrated fairness approach for adaptive governance.

Keywords
Adaptive governance; fairness; justice; integrated value assessment; contextual justice

Abstract
Resilience is now seen as a key concept to deal with large risks, such as climate change, faced by complex social-ecological systems. Resilience is mostly seen as not only the capacity to absorb shock and to maintain functions, but also the capacity for renewal and re-organisation while undergoing change (e.g. Folke, 2006). However, there is an important normative layer to resilience, which is often overlooked in the literature (see also Doorn, Gardoni, & Murphy, 2019). There are several normative aspects to resilience: the ultimate goal of creating resilience is inevitably partly normative (e.g. maintaining people’s welfare or capabilities); re-organisation can only be maintained if there is sufficient support, namely seen as acceptable and fair; changes creates distributive effects, for which there is no neutral default position; procedural justice and participation might generate more knowledge and possible more effective institutions; etc.

Therefore, a crucial question is how to design policy measures and create institutional change that is sensitive for moral concerns. If one is convinced of such a need, there seem to be two strategies: either one can apply theories of justice to the case at hand or one can organise a participation and deliberation process about the case. However, both strategies have their limitations. The rational and universal nature of ethical theories may not be suited for the particular context and may conflict with intuitions people hold. On the other hand, the outcome of a participation process will be sensitive to people’s opinions but may conflict with other moral concerns and, moreover, full deliberation might sometimes too time-intensive for all the re-organisation needed by a resilient system. What seems to be needed is a third approach, in between these two strategies.

Most theories of justice (e.g. Rawls, Dworkin) deal with 'distributive justice in the large' and do not engage with 'justice in the small', namely ‘concrete, everyday distributive problems’ (Young, 1995, p. 6). With regard to such local justice problems, fairness is to a large extent a contextual notion (Walzer, 1983), characterised by a plurality of principles that differs across spheres (Elster, 1992). Community standards of fairness often provide a good indication of which fairness norms are applicable to a particular situation, but they might be biased since it often concerns intuitive reactions (cf. Kahneman’s system 1 thinking). Therefore, what we need is a contextual account of fairness, namely a kind of reflexive equilibrium between community standards of fairness and more universal principles of justice. For this, we propose a three-step approach: (i) examine which norms are relevant for the case at hand (which system, which disturbances) (economics, engineering, law); (ii) examine to which extent these are perceived as fair (social science); and (ii) contrast these norms with general, widely supported justice principles (ethics). In other words, local fairness judgments might require, just as preferences in general, some laundering.

How such an approach can work is illustrated with a case study, based on earlier research (Neuteleers, Mulder, & Hindriks, 2017) namely the case of peak pricing for the electricity network. The combination of increasing variable electricity production (because of renewable energy) and increasing electricity demand, is challenging for the electricity network and peak pricing is proposed as one possible adaptive strategies. This case is particularly interesting because of the following tension: while there are strong efficiency argument for such peak pricing, research has shown that many people perceive it as unfair. Efficiency is defined by economics but fairness is more difficult to define and, moreover, not independent of the acceptability and feasibility of policy measures. If people think something is unfair, they will not support it or even protest actively against it. We will show how an integrated fairness assessment in this case can look like, based on combined insights from economics, behavioural sciences and ethics.

This paper argues that this approach can be applied and further developed for many governance strategies. The continuous adaptation and transformation of resilient systems needs to integrate fairness in its adaptive governance, for reasons of fairness, effectiveness and social stability. At the end of the paper, we will discuss next steps for the developing such an integrated fairness approach.

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Governing knowledge and knowers toward resilience and sustainability

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Summary

The two questions I raise in this presentation and paper center around how resilience planning ought to account for the role of epistemic agents—knowers—in their models. First, we need some idea of what kinds of knowledge will be needed for our resilience planning to work. Second, how can we ensure the communication and sharing of that knowledge when it is needed? I make a comparison here with sustainability to illustrate that it is not particular kinds of knowledge about the world we will need, but rather resilient knowers.

Keywords

community; ethics; normativity; responsibility; systems thinking

Introduction

When we think of sustainability, we also tend to focus on the knowledge gaps that arise. Part of sustainability is addressing the needs of the present without making it impossible for future people on this Earth to satisfy their own needs. But how do we know what will happen in the future, in order to prepare for that? And, how can we know what the future population of a region of the lobe will look like, in order to determine whether we have sacrificed their needs for our own, thereby not making sustainable decisions despite our best efforts? We cannot obtain the knowledge of the future we would need to fill these gaps themselves: we lack the knowledge about that future world needed to be able to say what causes will produce desired effects. Thus, the kind of knowledge we need to be sustainable is not certain knowledge, nor a simple knowledge of cause and effect that will allow us to predict better, but rather we need to be able to have complex and strategic knowledge that does not neglect this inherent uncertainty about our future.

Knowing for resilience

Future-oriented knowledge is knowledge about our present and about the past that allows us to make predictions about the future. We know of a cause and effect relationship from past experience; when we see causes in the present we can predict the effects will occur in our future. However, this kind of future-oriented knowledge does not actually help when the effects we experience differ from our predictions. Thus, there is a difference between planning with the future in mind, as sustainability models emphasise, and planning for coping with and responding to the unexpected (and unpredicted), as resilience models attempt to do. Resilience requires a different kind of knowledge than future-oriented knowledge, but it is no less complex and strategic. In both cases, the knowledge itself remains open in terms of content, because of the inherent uncertainty involved. We cannot say exactly what effects we need to cause for a sustainable future; we cannot say exactly what knowledge will enable the best (resilient) response to an unexpected crisis.

I argue that, when we do not know what unpredictable things will happen, we need to prepare ourselves as knowers, rather than prepare ourselves with the right kind of knowledge. Let's focus on resilience. In an unexpected crisis (shock or stressor), what will be the right kind of knowledge to resolve the crisis emerges from the crisis itself: only when we can predict what will happen, can we predict what kinds of knowledge will be needed, so to the degree that an event is unpredicted is the degree to which we will be uncertain, beforehand, about what kinds of knowledge we will need. For instance, in resilience planning, one tactic is to create redundancies in a technical system so that if one part of the system fails, another part can take its role in the system and keep the system going as a whole. When it comes to knowledge, we could think in terms of redundancy. For instance, having multiple people available trained in the same thing, so that if one of them does not show up there will still be an expert where needed. However, this assumes we can predict what kinds of knowledge will be needed at the time—

rather than a responsive approach, this is a cause-and-effect or future-oriented approach to planning then. One this this presumes is that the system itself (and thus the knowledge needed to keep it going) will remain stable, or at least will 'bounce back' to its former state in important ways. But this is not in keeping with current understandings of resilience, even within engineering, that emphasise instead adaptability and even transformability—responsiveness—as key aspects of resilient systems. What kind of multidisciplinary team can be responsive to any given disaster, crisis or stressor? We cannot know ahead of time what knowledge will be needed at that time, so if we see the people who know as fungible (potentially redundant) containers of that knowledge it is difficult to see how they will also be sufficiently responsive in the face of unpredictable demands.

Therefore, I propose, it would be better to shift our focus from the knowledge to the knower, and even more importantly, to the systems of knowledge generation and exchange (epistemic communities), in order to ground the resilience of knowledge systems in adaptability rather than redundancies. This move is in keeping with approaches in resilience engineering that emphasise a shift away from redundancy and 'bouncing back' approaches to resilience and toward flexibility and adaptability in 'bouncing forward' approaches to resilience.

What, then, would a resilient epistemic community (community of knowers) look like? Redundancy is based on the view of knowledge as being held by individuals and shared between individuals; one comes to know something, and then passes on that knowledge or demonstrates it as a skill. The knowledge is thus found in the individual and moves between individuals, and the responsibility for knowing and sharing is taken up or put upon individuals who know. However, the ability to acquire and transfer knowledge is not what will be useful in a crisis – under an adaptability model, one also needs skills in recognizing what knowledge will be needed in the moment and as events unfold, identifying other knowers or those who need to know (to share one's knowledge with), and using knowledge in ways that are novel and even surprising. On a system level, a community of knowers (epistemic community) that can interact in adaptive ways in response to a crisis will be more likely effective than a system of knowers that have stable roles in that community and are unable to change roles quickly.

To give an example. In January of 2014, a fire nearly destroyed the small, historic town of Laerdal in Norway. The extent of the damage was partly due to the distance that additional fire services had to travel to reach the town; the reason the whole town was not destroyed has been credited to the local knowledge and quickly adaptive response of local administrators and citizens. In a particularly vivid example, there were reports of manure spreaders thundering down the valley to be used as alternative fire hoses. As Andresen (2020) points out, this local response required a network of people who knew each other, knew how to use farm equipment and could think through how to use it differently in an adaptive response requiring collaboration (Andresen, S. 'Contesting scale: A space of the political in a post-disaster context' *Political Geography,* 81:102203*,* 2020). Perhaps, as folklore would have it, the kinds of collaborative, communicative and creative epistemic skills in place in this small community emerged naturally from social relations—the tight bonds of a small, isolated, agricultural town. At any rate, they ought to be part of our conception of resilience planning, and their epistemological characteristics bear exploring and analysis.

Strategic epistemology

In sum, I am suggesting that to be strategic about knowledge, we need to be strategic about *who* might know as well as *what* we need to know at the time. Further, we need to consider *how* that knowledge will be communicated, and *how* it may need to adapt. So it is not just about having the right knowledge to hand when the moment arises, but also having the tools needed to effectively share that knowledge and how to generate new knowledge through sharing in the moment of need (and in response to the crisis at hand). For the purpose of this talk, I consider one idea for an approach to finding indicators for this kind of *epistemic* resilience: diversity, rather than redundancy. And finally, reflecting on contemporary approaches to resilience that take up questions of justice and capabilities, I suggest that resilience and sustainability, when we think in epistemological terms, are again significantly alike. In both cases, we need to prepare society to be a society of capable knowers, with skills that allow them to adapt to changing circumstances: in the case of resilience, the focus is on current populations, and in sustainability, this requires a long-term investment in the education of, as well as resource management on behalf of, future generations.

Deciding for tomorrow, today. What makes governmental decisions about water infrastructure forward looking?

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Summary
This paper aims to assess, explain, and improve the extent to which governments make forward-looking decisions about their water infrastructure. Because many water infrastructure assets are reaching their end-of-lifetime, governments therefore need to invest in the replacement and renewal of current infrastructure or in entirely new infrastructure. To anticipate changing future developments, governments will need to make forward-looking decisions but this can be especially challenging because of governments' short budget and election cycles and their accountability to current constituents. The general research question was formulated as: What makes governmental decisions about water infrastructure forward looking? The paper develops a new framework that provides: (1) The criteria for, and measurements of, a forward-looking decision; (2) The enabling conditions of forward-looking decisions that characterize the decision-making context; and (3) The five main interaction processes that shape the extent to which governmental investment decisions about water infrastructure become forward looking.

Key words
Water infrastructure; forward-looking decisions; strategic agility; decision making; governance

Introduction
This paper aims to assess, explain, and improve the extent to which governments make forward-looking decisions about their water infrastructure. Forward-looking decisions are especially relevant because many water infrastructure assets are reaching their end-of-lifetime due to technological ageing and changing functional demands. Governments therefore need to invest in the replacement and renewal of current infrastructure or in entirely new infrastructure. The long lifespan of water infrastructure requires governments to take into account possible impacts of developments such as climate change, economic developments, and demographic changes. Furthermore, governments worldwide have committed themselves to international agreements focused on addressing long-term problems such as freshwater availability and climate change mitigation. Implementing such agreements requires national and local governments to exploit investments in end-of-lifetime infrastructure to achieve specific long-term objectives. Governments therefore need to think carefully about the future when they are preparing to invest in water infrastructure. They need to consider the relevance and impact of possible future developments for infrastructure and the potential contributions of infrastructure investments to addressing long-term problems. To ensure that infrastructure can cope with changing circumstances and to achieve sustainable and resilient societies, governments need to choose infrastructure that can remain effective across that infrastructure's lifetime. This requires governments to make forward-looking decisions. This paper introduces forward-looking investment decisions as decisions in which governments anticipate possible future developments that could impact the long-term effectiveness of water infrastructure. Forward-looking decisions can enhance resilience by selecting infrastructure that can cope with disturbances but also by using infrastructure to transition to more desired future states. Making forward-looking decisions can be especially challenging for governments because of their short budget and election cycles, their accountability to current constituents, their responsibility to provide legal certainty, and their focus on short-term results.
The general research question was formulated as: What makes governmental decisions about water infrastructure forward looking?

Results
The multi-method research design of this paper, that combined ethnography, process tracing, and qualitative comparative analysis, enabled complementary answers to be found to the main research question of What makes governmental decisions about water infrastructure forward looking? The answer consists of the following three parts:

1. The criteria for, and measurements of, a forward-looking decision that define whether a governmental investment decision can qualify as forward looking
The main criteria for a forward-looking decision focus on three elements of a governmental decision. These elements are the agreed-upon problem definition, the chosen solution, and the justification for the decision. The criteria are as follows:

- The problem definition is forward looking when it refers to long-term challenges and includes a long time horizon to discuss these long-term challenges.
- The chosen solution is forward looking when it is robust, flexible, or both to remain effective under a range of future circumstances. Robust solutions are solutions that can maintain their critical functions, even when stress-tested against different and extreme-case scenarios. Flexible solutions are solutions that can be adapted to changing insights and circumstances, and for which a monitoring system is in place to detect and respond to changes in a timely manner.
- The justification of the decision is forward looking when it relies on scenarios to understand possible futures and/or on visions or long-term objectives that formulate desirable futures.

Based on these criteria for a forward-looking decision, it is possible to measure the extent to which governmental investment decisions about water infrastructure are forward looking.

2. The enabling conditions of forward-looking decisions that characterize the decision-making context
This paper adopts the streams metaphor from the garbage can model and the multiple streams framework to reveal the dynamic and often ambiguous decision-making context in which actors operate. The streams relevant to understanding decision-making processes are the politics stream, the problems stream, the solutions stream, and the choice opportunities stream. These streams provide the conditions of the decision-making context. Conditions are the relatively fixed characteristics of organizations and the reality outside organizations that actors cannot directly influence during decision-making processes. Different combinations of conditions can create a decision context that enables governments to make forward-looking decisions. This paper found that combinations of the following conditions from the four streams can enable forward-looking decisions:

- Problems stream: Experience with extreme weather events (focusing events) and collaborative opportunities from the external environment;
- Politics stream: Long-term-oriented or collaborative political leadership, perceived political risks, and the end-of-election cycle;
- Solutions stream: Organizational analytical capacity of water management departments, organizational size (as reflected in the number of inhabitants belonging to an administrative area), and water infrastructure reaching its end-of-lifetime;
- Choice opportunities stream: The end-of-budget cycle, legislation and agreements prescribing long-term objectives, scenarios, performance requirements, and legislative organizational responsibilities for the long term.

3. The strategies and mechanisms that can be clustered into five main interaction processes that shape the extent to which governmental investment decisions about water infrastructure become forward looking

Individual and organizational actors respond to the decision-making context by developing strategies. A strategy is understood as a set of actions that display a certain pattern that can remain quite stable across time. By choosing or using specific strategies, actors influence the forward-lookingness of investment decisions. Strategies can become part of mechanisms. Mechanisms are the causal processes that link conditions to the outcome of a forward-looking decision and provide direct explanations for this outcome. Mechanisms and strategies together form the interaction processes between organizations and within organizations. These interaction processes can therefore be both intra-organizational and inter-organizational:

- Intra-organizational processes emerge from the interactions between actors that belong to the same governmental organization. Three intra-organizational processes can be distinguished: framing specific long-term problems or objectives; selling of the long term by civil servants in political decision-making venues to ensure enduring commitment to long-term policies and action plans; and complying with existing standards that prescribe long-term investments, objectives, future scenarios, responsibilities, and long-term performance requirements for infrastructure.

- Inter-organizational processes emerge from the interactions between several organizations. Two inter-organizational processes can be distinguished: minimizing future risks to avoid system failure or disinvestment; and collaborating to achieve desired long-term objectives or long-term solutions.

The following figure provides an overview of the conditions and interaction processes that contribute to forward-looking decisions.

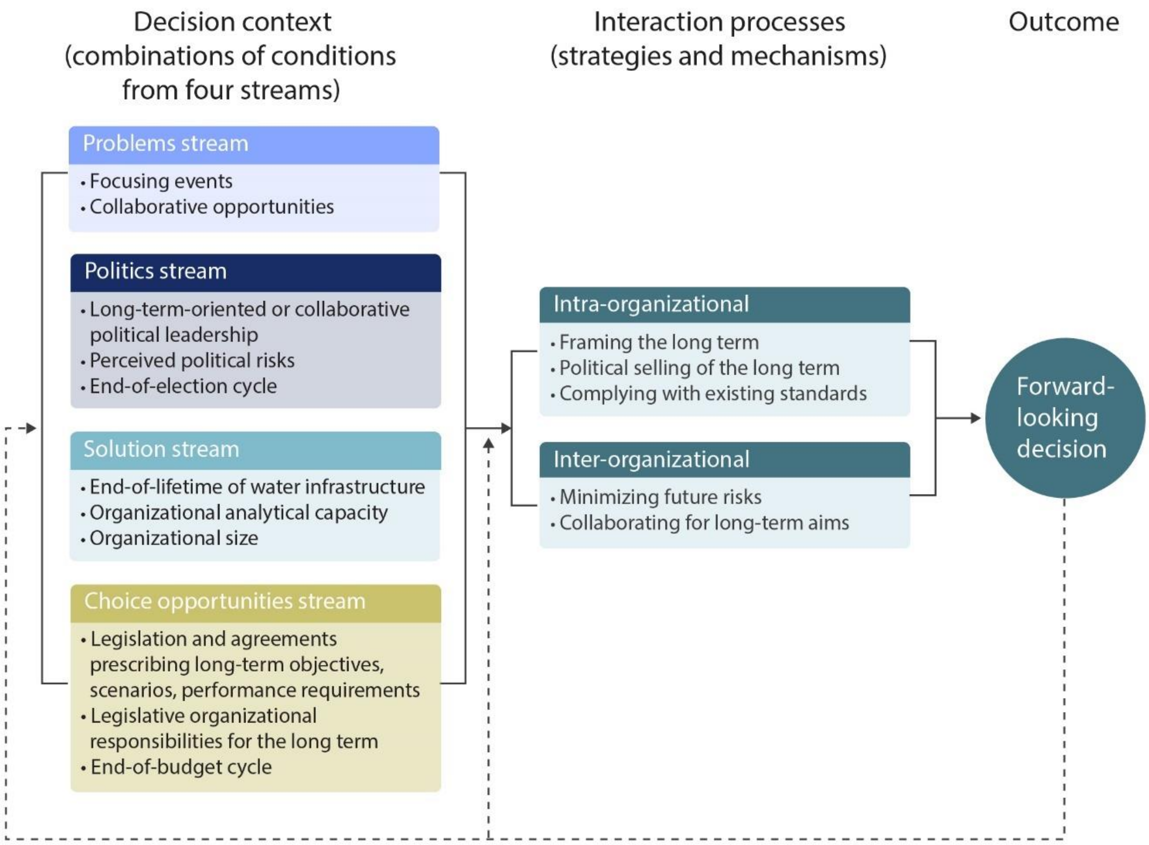

Figure 1: Overview of conditions and processes behind forward-looking decisions

Conclusion

The paper introduces the novel concept of a forward-looking decision and presents a new theory of forward-looking decision making. The theory can be used to assess, explain, and improve the extent to which governments make forward-looking decisions about their water infrastructure, by respectively:

- Applying the criteria for a forward-looking decision to assess governmental decisions;
- Providing the combinations of conditions and processes that explain how investment decisions become forward looking; and
- Using the criteria for a forward-looking decision to prepare investment decisions and using the causal mechanisms to provide recommendations for improving the governance capability for making forward-looking decisions.

Forward-looking decisions are essential for resilience, since they (1) result in infrastructure systems that can cope with disturbances and change; and (2) utilize the opportunity of infrastructure investments for transitioning to more desired future states of the infrastructure system and beyond. The measurements of a forward-looking decision create the possibility to measure the adoption of flexible and robust solutions and the use of future visions and scenarios as part of governmental decisions. Applying this to infrastructure investment decisions reveals the extent to which, and the reasons why, governments use methods and tools to support decisions about long-term solutions and long-term problems. This contributes to scholarly debates about the use of decision support methods and tools by governments, and about the presence of governmental myopia. The paper shows that forward-looking decisions are possible within present-day governmental settings characterized by annual budget cycles and four-year election cycles. The results also show that governments still focus strongly on risks instead of on uncertainties when deciding upon infrastructure investments, by avoiding references to the concept of uncertainty and by using future scenarios and flexible solutions only to a limited extent.

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Governance systems and institutional arrangements for STE resilience
D.s16. Building STE system resilience through Institutions & Governance: Reflections from theory and practice

Informing the governance of STE resilience by integrated and normative perspectives

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Summary
There is a need to approach the concept of resilience from a more integrated as well as normative perspective. It cannot be a purpose in itself and it relates to a variety of phenomena which need to be taken into account explicitly. Resilience cannot be an alternative for a sustainability focus; rather the two concepts represent two mutually complementing perspectives. This paper presents opportunities which the theory of modal aspects (TOMA) offers for developing such integrated and normative perspectives on resilience (innovations) in the context of sustainability ambitions. It demonstrates TOMA's potential to inform model design and selecting indicators for evaluating STE resilience, and to generate rich perspectives on what needs to be considered conceptually and practically in making resilience work for sustainable development.

Keywords
Resilience Capacity; Resilience Thinking; Sustainability; Vulnerability; Multi-Aspectual Analysis

1. Introduction

In this paper, we explore two areas of thinking in relation to resilience: normative perspectives, and integrated perspectives. In combination, we apply this towards a governance perspective on making resilience work for sustainable development (cf Joseph and McGregor, 2020; Marchese et al. 2018). Our exploration is guided by the theory of modal aspects (TOMA) and this paper seeks to examen its usefulness in this context.

Resilience is not a purpose in itself. Related processes of absorption, adaptation, and transformation (Folke et al. 2010; Meuwissen et al. 2019) are meant to serve a purpose, which is often referred to as being able to continue to achieve desired system functions such as stability, security, or sufficiency. This leads to two questions: what type of things can be resilient, and what type of system functions may be served through resilience? We argue that creating a systemic perspective on such typologies would serve resilience innovation and resilience engineering in two ways. First, by providing integrated perspectives on the types of things that can be resilient or lack resilience, and by doing so help to create an overview regarding options for building system resilience. Second, by informing normative perspectives on the types of system functions that may be served through resilience by clarifying which functions are and are not served, as well as related trade-offs (cf. Keessen et al. 2013). For example, building climate resilience through a focus on maintaining certain production levels, may come at the expense of maintaining fair distribution of benefits between different groups in society.

In the following, we briefly introduce TOMA, then illustrate examples of its use in the context of resilience and sustainability concerns (cf. Gillespie-Marthaler et al. 2019), and we close with a reflection on the relevance for considering the relation between institutions and governance arrangements, and STE system resilience.

2. The theory of modal aspects (TOMA)

TOMA is based on a number of premises which are informed by observing patterns in everyday experience. First, it argues that all entities – though in different ways – can be evaluated from the perspective of each of the aspects presented in Figure 1 (Basden, 2019; Brandon and Lombardi, 2010; Wigboldus and Jochemsen, 2020). They are referred to as modal aspects because they relate to a category (modality) which cannot be described by a single word. Second, it argues that distinguishing aspects serves to order our perception of reality and helps to identify ways in which things do or do not make sense (Basden, 2019). Whether formal or informal, all analytical thinking presumes a set of aspects (Basden, 2011). This way of understanding the world is conducive in particular to the various scientific disciplines that tend to take a particular aspect of everyday experience as their focus of study. Third, the 15 aspects follow a particular order that build up gradually from first (quantitative) to last (pistic). Each aspect is distinct from all others, precluding reductionism, yet each aspect coheres with the others in various ways (Basden 2019). Things (entities, processes) function in all aspects simultaneously and no aspect undermines any of the others as they are considered equally important.

Modal aspects	Related basic questions	What resilience innovations may relate to, e.g. changing ...
Quantitative	How many?	... numbers and amounts
Spatial	Where? How big?	... locations, scales, and patterns of spreading
Kinematic/ kinetic	Is there movement? Where, how fast, in what direction?	... flows and networks
Physical	What substance, what energy levels?	... levels of energy (supply) and non-organic resources
Biotic	What forms of life present?	... thriving?, growth rates, yields, organic resources
Sensitive/ psychic	How perceived?	... feelings, perceptions and observations
Analytical	What distinctions can be made?	... ways of conceptualising
Formative	How can be intervened?	... ways of shaping social and physical reality
Lingual/ symbolic	What are meaningful symbols?	... ways of framing, communication
Social	What social interaction/ communion?	... social relationships, participation
Economic	What are ways of efficient provision?	... way of efficient provisioning; adding value
Aesthetic	What is enjoyed, cherished?	... what is enjoyed, appreciated
Jural	How to give each its/his/her due?	.... regulations, laws and their implementation
Ethical	What is considered to be good?	... sense of responsibility, accountability
Pistic/ fiduciary	What are the beliefs, the values?	... core motivations, paradigms

Figure 1: A brief outline of the fifteen aspects of the theory of modal aspects (adapted from Wigboldus and Jochemsen, 2020)

3. Results

Wigboldus and Jochemsen (2020) discuss a perspective on fifteen aspects of sustainability and how an integral approach to leveraging sustainability transformations (cf. the seventeen Sustainable Development Goals) needs to simultaneously pay attention to each of these aspects of sustainability. Exploring system functions along the lines of the fifteen aspects shows a clear overlap between system function orientation and a sustainability orientation (Figure 2). Thus, it offers a systemic perspective on the connection between resilience (as property) and sustainability (as purpose).

Modal aspects	Types of (STE) vulnerabilities	Types of resilience (capacity)	**Purpose orientation:** System functions and related sustainability aspirations
Quantitative	Fragile basis for sustaining sufficiency in terms of e.g. financial assets	Ability to maintain/restore needed amounts (e.g. quantitative buffers)	Sufficiency
Spatial	Fragile basis for sustaining needed space, volume, land	Ability to maintain/restore needed space	Proportionality, scalability, land security
Kinematic	Fragile basis for sustaining movements and mobility	Ability to maintain/restore needed movement, mobility	Circularity, mobility, continuity/ constancy, flexibility
Physical	Fragile/sensitive structures, materials, and sources of energy	Ability to acquire, maintain/restore needed energy, materials and structures	Sourceability, availability, accessibility
Biotic	Fragile basis for sustaining life (functions), ecosystems, health	Ability to maintain/restore needed life functions, ecosystem functions/ services	Biodiversity, health (security)
Sensitive	Fragile/sensitive basis for sustaining e.g. mental health	Ability to maintain/restore needed sound perceptions, emotions	Sensibility, security; mental health; proper functioning of senses
Analytical	Fragile basis for obtaining and sustaining knowledge, sense-making and understanding	Ability to maintain/restore needed clarity of understanding	Validity, factuality; clarity of concepts and theories; proper functioning of mind
Formative	Fragile/fractured basis for sustaining production processes; lack of adequate technology	Ability to maintain/restore needed production/ construction supporting factors	Functionality, productivity, utility; adequate, responsible technology
Lingual	Fragile basis for sustaining clear symbols, communication, and interpretation	Ability to maintain/restore needed proper interpretation, and communication quality and channels	Intelligibility, evidentiality; proper interpretation and translation
Social	Fragile/sensitive basis for sustaining social interaction/ relationships; Disfunctioning social structures	Ability to maintain/restore needed social interactions	Inclusiveness, equity, well-functioning of adequate social structures,
Economic	Fragile/sensitive basis for sustaining prudent provisioning	Ability to maintain/restore needed efficient provisioning	Affordability, efficiency, caring and sharing
Aesthetical	Fragile/sensitive basis for sustaining beauty and enjoyment; harmonious development	Ability to maintain/restore needed beauty, enjoyment, recreation	Appeal, beauty, recreation, harmony
Jural/ Juridical	Fragile basis for realising justice, sustaining law and order and/or regulatory frameworks	Ability to maintain/restore needed law and order; community acceptance of proper functioning judicial system	Legality, legitimacy; Implementation of justice; positive law is serving justice
Ethical	Fragile basis for sustaining norms, accountability, love and solidarity	Ability to maintain/restore needed love, solidarity, accountability; moral capital	Accountability, responsibility, integrity (norms)
Pistic/ fiduciary	Fragile basis for sustaining trust, hope, and commitment to values	Ability to maintain/restore needed fundamental trust and hope	Trustworthiness, providing hope, committed to core values; freedom of conscience

Figure 2: Creating an integrated perspective on vulnerability, resilience and sustainability using TOMA

Applying the philosophy underpinning TOMA implies that resilience of any entity is vested in resilience capacity related to each of the modal aspects. Thus, it may open eyes to opportunities for strengthening resilience in quite other ways than common approaches tend to highlight. Also, it alerts to reductionist perspectives of narrow resilience which is only focusing on resilience in some aspects without paying due attention for resilience in other aspects. Figure 3 illustrates how TOMA can help create a dynamic perspective on the way in which a resilience response to a particular (exposed) vulnerability may address a particular sustainability concern, while putting another sustainability concern at risk. An overview such as this table may help as a reference framework in considering the appropriateness of introducing resilience innovations.

Modal aspects	**Typical (STE) vulnerabilities**	**Related resilience response (innovation)**	**Related sustainability focus**	**Resilient sustainability perspective**
Quantitative	Limited/ vulnerable stocks	Change in terms of quantities (numbers)	Sustaining sufficiency	
Spatial				Sufficiency where?
Kinematic				How regenerative is this sufficiency?
Physical				Sufficiency of what exactly?
Analytical				How sure are we that this is sufficient, and for how long?
Social				Sufficiency of what for who exactly?
Economic				How efficient?
Jural/ Juridical				How legitimate?

Figure 3: Example of considering implications of particular resilience innovations for different system functions and related sustainability concerns

Figure 4 illustrates opportunities for using TOMA to create a dynamic, integral perspective on shocks/stresses resulting from extreme events, and the cascading effects and related multiple resilience needs. For example, COVID-19 began as a biotic shock, but gradually created shocks in all 15 aspects, testing resilience and exposing vulnerabilities in all related domains.

In the same way as scientific disciplines take particular aspects as their focus, leading to the need for interdisciplinarity, different institutions and governance arrangements will take particular aspects as their focus. Sustainability concerns, resilience needs, and related trade-offs will need to be considered across different scales, across different spheres of life, and across stakeholder interests. This requires a consistent perspective that can be applied across such different dimensions. TOMA offers opportunities for doing so. Though based on a particular ontology that distinguishes the aspects in all things, it does not have any underlying political orientation, thus enabling the characterization of any such orientation along the lines of the aspects.

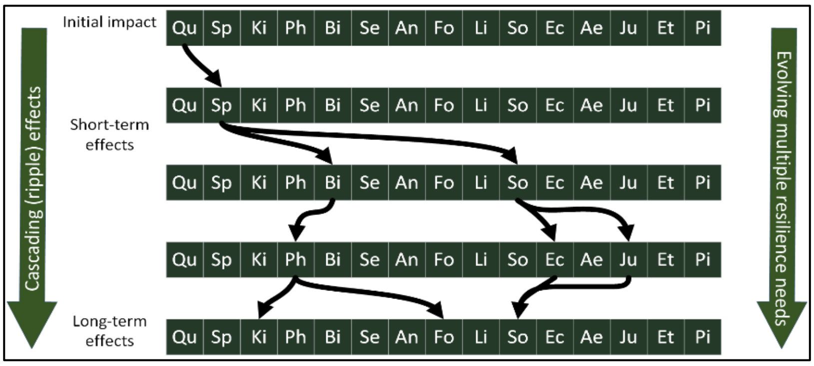

Figure 4: Using TOMA to create unfolding narratives to explore multiple resilience needs in response to extreme events (source: the authors)

4. Discussion

The application of TOMA in the field of resilience thinking illustrates its usefulness in creating systemic perspectives on a variety of ways in which resilience can work for sustainable development. It offers a reference framework for identifying the focus (and what is not part of the focus) of different approaches to resilience engineering. This may also reveal particular underpinning ideological and political orientations (Chandler, 2014; Humbert and Joseph, 2019).

TOMA offers opportunities for systemically and systematically exploring the way in which institutions and governance enable and/or constrain resilience and what this means for needed designs and interventions. It may be used to explore how institutions and governance arrangements 1) *inform* priorities and trade-offs made in relation to system functions, how they 2) *influence* (e.g. contribute to) STE system vulnerability, and how they 3) provide capacities and opportunities which may be *access*ed to build and sustain STE system resilience (Figure 5). In similar ways it can help to explore implications for resilience response options (e.g. providing new opportunities for adaptation or transformation).

Brandon and Lombardi (2010) used TOMA to systematically and systemically evaluate sustainable development in the built environment. In similar ways, TOMA may be used to evaluate ways in which institutions and governance arrangements shape and/or constrain conditions for STE system resilience.

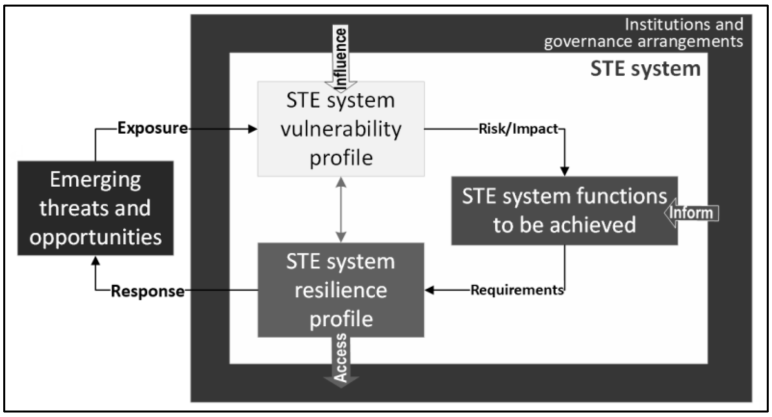

Figure 5: TOMA offers opportunities for systematically unpacking dimensions of STE system resilience (source: the authors)

5. Conclusion

Getting to grips with the concept and practice of resilience requires activating integral perspectives on types of resilience, as well as enabling normative perspectives on what resilience is meant to serve (in terms of system functions and related sustainability concerns). This also applies to creating an appropriate understanding about the way in which institutions and governance arrangements inform, influence, and provide opportunities for STE system resilience. In this paper, we explored opportunities that the theory of modal aspects (TOMA) offers in relation to this. The next step will be to translate this conceptual perspective into practical applications.

Acknowledgements

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Do we need disaster to prepare for climate change? The impact of natural disasters on local political agendas exemplified by flood events in Switzerland

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Summary
Climate change urges for policy changes today that support societies in their ability to adapt to increasing flood risks in the future. Rather than anticipating upcoming challenges, however, policy change is often reactive, being adopted in response to natural disasters. We scrutinize the factors determining whether regional parliaments address the topic of flood protection on their agendas by taking the case of Switzerland—a country in which climate change-induced floods are projected to cause a high level of concern in the future. We distinguish precautionary drivers of policy change, e.g., learning, from reactive drivers, i.e., the occurrence of damaging flood events. Our results show that parliamentary sessions addressing floods are most likely after flood events with large damages, but that also the publishing of scientific reports and national policy change can initiate discussions on precautionary flood protection in some cases. Findings call for parliamentary action to 'govern for resilience`, which entails preparing societies for upcoming challenges of climate change and, thereby, improve the resilience of societies.

Keywords
climate change adaptation; floods; policy change; shocks; policy learning; agenda-setting; parliaments

Introduction
Resilience can be defined as the *long-term* capacity of a system to deal with change and continue to develop (SRC 2014). Dealing with floods, for example, demands long-term investments and planning. Those investments heavily depend on policy and budgetary decisions by parliaments. Parliaments, by contrast, depend on short-term electoral cycles. Conflicts between short- and long-term planning in democracies is one of the central points of concern in resilience thinking. In this paper, we contrast short-term planning where parliaments react to sudden flood events to long-term planning where parliaments take precautionary measure to mitigate potential future flood events.

Precautionary versus reactive policy change
Climate change calls for policy decisions in various sectors where the risk of natural hazards is increasing. One such sector is flood protection. Public policy literature has shown that policy change is often triggered by natural disasters. These results highlight that policies are often adopted reactively, i.e., in response to disasters, rather than in a precautionary manner. The policy change literature also describes alternative pathways to policy changes through learning. Learning can occur, for example, by copying other political entities' flood policies; or after the publishing of (scientific) reports on risks and damage of floods. In reaction to those reports, parliamentary actors may adopt policy change in order to prepare for future flood events.
By taking the case of Switzerland, we contrast reactive to precautionary policy change and ask: Which factors determine whether local Swiss parliaments address the topic of flood protection on their agenda? We distinguish precautionary drivers of policy change, including the publishing of scientific reports and national-level policy changes, from reactive drivers, i.e., the occurrence of damaging flood events.

Data & empirical analysis

We created a dataset of cantonal parliamentary sessions and analyzed the occurrence of sessions addressing floods. Additionally, we created a dataset of Swiss flood reports and national policies. We then investigate the drivers of agenda setting by combining a logistic regression analysis, an egocentric relational event model and a descriptive analysis. Our results show that parliamentary sessions addressing floods are most likely after flood events with large damages, but that also the publishing of scientific reports and national policy change initiate parliamentary discussions on flood protection in some cases. Additionally, we show that cantons differ considerably in their reaction to damaging flood events.

Results & Conclusion

The results indicate that flood protection policies are mostly adopted reactively in the analyzed cases. We find that learning from scientific reports and national policies only happens occasionally.

These findings are in line with policy studies, which have found that parliamentarians' use of science to inform their policy-making is often lacking (Holms and Clark, 2008; Howlett, 2009). Other studies also indicate that even when policymakers consider science, they do so in a restricted manner (Lövbrand, 2011). As a means to improve the uptake of science in policymaking and enable proactive policymaking, Cairney and Wellstead (2016: 399) argue that not only the supply of information to policymakers is important. They state that the "wider process of debate, coalition formation, and persuasion to reduce *ambiguity* by establishing a dominant way to "frame" policy problems [which] can determine the demand for scientific evidence" should also be addressed.

Our findings can be used as an entry point to reflect on parliamentary agendas, their contribution to prepare for climate change in the long-term and, thereby, improve the resilience of societies. Moreover, it provides a basis for subsequent research on agenda setting and policy change on a local level regarding climate-related topics.

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How to foster resilience? – an analysis of adaptive governance for aquatic STE systems

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Summary

Adaptive governance enables actors to respond to complex dynamics and to prepare for resilient systems against future changes. We investigate three cases of aquatic STE systems to analyze how actors collaborate to implement technical solutions to environmental problems and change their governance structure to address the systems' complexities. Climate change affects lake freshwater quality and quantity in several ways: eutrophication, ecological time lags, feedbacks and trade-offs among interest groups. These phenomena challenge lake management and the provision of multiple services. We study how engineering elements may buffer climate change effects and how actors foster system resilience.

Keywords

Social-technical-environmental system; social-ecological systems; adaptive governance; system resilience; Causal Loop Diagrams.

Introduction

Actors participating in a social-technical-environmental (STE) system encounter at least two challenges: (a) comprehending complex dynamics, interdependencies, and emergent patterns of the STE system and (b) creating a governance structure that enables system resilience to gradual and sudden changes, and external influences. We focus on lake ecosystems with human-induced environmentally engineered characteristics that regulate water quantity and quality, and on the network of regional stakeholders involved in the STE system management.

Climate change is a major long-term change STE systems face, leading to higher lake water temperatures, increased evaporation and concentrations of nutrients and pollutants; factors potentially destabilizing the systems state. Especially the latter can cause a sudden regime shift from a clear to a turbid water state, dominated often by toxic cyanobacteria.

Given these threats, we assess (a) how the elements of the aquatic STE system and their interactions intensify or buffer climate change effects and (b) whether the environmental governance system is able to ensure system resilience.

Theory and Conceptualization

Our work is based on social-ecological systems (SES) and understands resilience as the capacity of a system to persist, adapt and transform to maintain its key functions (Folke et al. 2016). To achieve SES resilience, actors need to be able to adapt their management modes to changes and disturbances occurring in the ecological and social system (Biggs et al. 2015; Folke et al. 2005; Pahl-Wostl 2009). Scholars highlighted the need of the social system to "(…) respond to environmental feedback, to learn and store understanding, and be prepared and adaptive to allow for change." (Folke et al. 2003). One way to do so is through adaptive governance. Becoming more explicit on the technological aspects within an SES, e.g. by specifying the use of infrastructure, engineered or information technology, we extend the understanding of SES resilience to STEs in line with previous conceptualizations on technology (Markolf et al. 2018). When governing a resource and its system, actors often actively account for technical interventions to address environmental problems. Based on Folke et al. (2005), we understand adaptive governance as the management of an ecosystem and the "(…) broader social contexts that enable ecosystem-based management". It enables actors to understand resource and ecosystem dynamics, align their management actions accordingly, learn from their actions and account for uncertainties.

Method

We analyze interviews with actors of the governance system in three case study regions guided by the criteria of adaptive governance (cf. Folke et al. 2005). To identify how the governance structures contribute to STE system resilience, we discuss the results in light of the STE system analysis.

We develop Causal Loop Diagrams (CLDs) to depict the critical interacting elements of the STE systems. These diagrams connect cause and effect variables via arrows, thereby forming causal chains (Inam et al. 2015), enabling modelling of system dynamics.

Case studies

Lake Dümmer and its lowlands in Northwestern Germany is a system with a heavily regulated hydrology that enables diverse recreational activities, assures flood protection and protects biodiversity. The lake is in a eutrophic state owing to agricultural runoff. Lake Saint-Charles (Canada) and Lake Ringsjön (Sweden) both serve as drinking water sources while also supporting biodiversity and recreational activities. In the case of Lake Saint-Charles, the people benefiting from the drinking water live in the City of Québec, outside the municipality of the lake, leading to political conflicts between municipalities over the control of the resource. Lake Ringsjön in Southern Sweden has been restored to a less eutrophic state (related to agricultural activities) for about 20 years. To restore the clear water state, trawling of whitefish was the main intervention applied; but effects from angling, vegetation planting and wastewater treatment in the catchment are considered in future plans. In all cases, diverse actors collaborate to safeguard the lake states.

Preliminary results

At Lake Dümmer, we observe an SES influenced by two engineering elements. A dyke around the lake serves the flood protection and maintains a water level suitable for water sports. The dyke drained large parts of the lake's lowlands which provide habitat for endangered bird species. Thus, a lock and canal system was installed to water them. Both engineering elements potentially buffer heat wave effects associated with climate change by storing dammed water and ensuring a steady water supply to the wetlands. However, these mechanisms may fail when the tributary does not carry enough water. Lake Dümmer is eutrophic owing to agricultural activities in the watershed and with increased evaporation, the lake will most likely experience even higher future phosphorus concentrations.

The governance of the lake and its lowlands is orchestrated by a council. The council advises on the implementation of a remediation strategy which aims to reduce phosphorus loading. Currently, measures ensure a minimum level of ecosystem service provision. The governance system does not enable ecosystem regeneration, which thus maintains its functioning with difficulty.

In lake Saint-Charles, eutrophication, increased water demand, higher popularity of water sports, and increased pressure for residential development are predicted to be the main effects associated with climate change. Most actors agree that engineering solutions – modernisation of wastewater treatment plants and septic tanks; the junction of septic tanks to the municipal sewage; and the junction of water treatment plants downstream of the water intake – will be the more effective ways to solve eutrophication issues. However, until recently, the top-down approach taken by the Metropolitan Community of Quebec (MCQ) largely hampered efforts to develop solutions because of imposed regulations that led to social and legal conflicts, and to higher pressure on the lake as a result of accelerated residential development. Nevertheless, a new approach has been adopted by the MCQ in 2018, and the governance system is slowly shifting from a top-down to a more integrated approach.

This transition suggests that learning occurred among decision-makers, with new cooperative measures reminiscent of Folke et al. (2005)'s categories of adaptive management.

Restoration activities at Ringsjön demonstrate first effects to improve the clear water state. Simultaneously, it remains uncertain the degree to which investments are sufficient to reinforce clear lake dynamics and whether they will be able to withstand climate change effects. Diverse interventions such as angling regulations and improvement of private wastewater treatment are considered to accelerate restoration and secure lasting effects. We analyzed interview data and interpreted past policy cycles to support biomanipulation as part of the first learning loop (Fig 1) during which the duration and extension of biomanipulation was discussed.

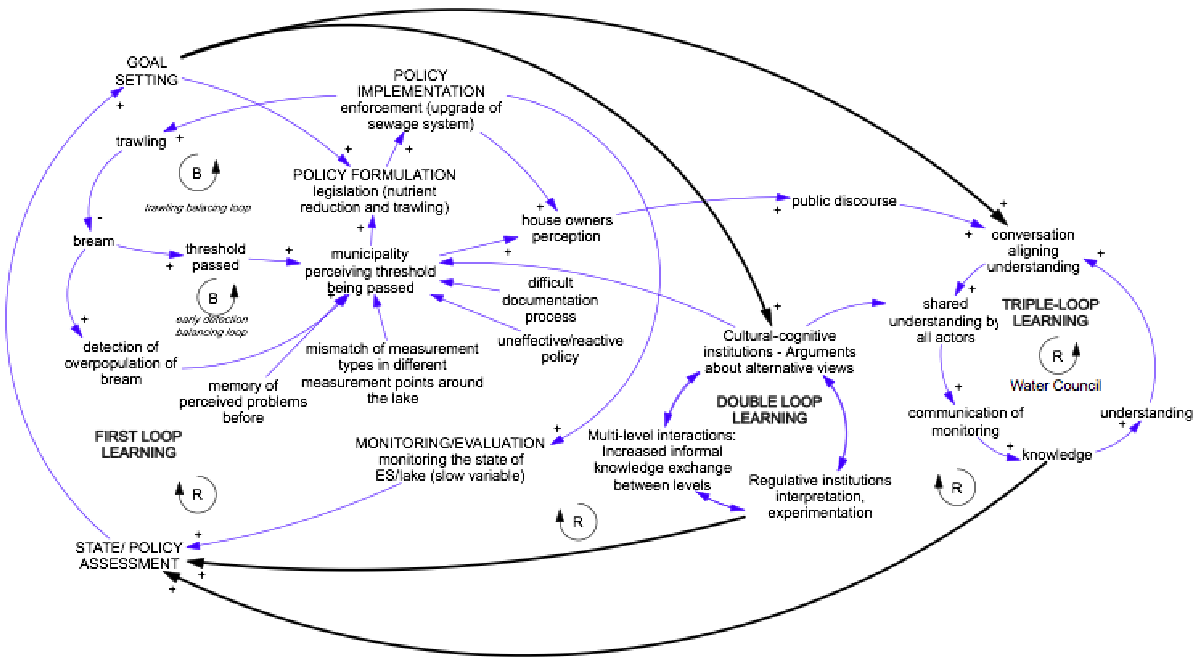

Figure 1: CLD representing institutional learning loops with adaptive governance focusing on trawling to restore the clear water state at lake Ringsjön.

Considerations of whether the biomanipulation measure is sufficient are placed in the second learning loop (goal setting). They concern increasing interests in angling, continued inflow of nutrients, expected heavy rain events due to climate change, and how these could be buffered through additional restoration measures. The third loop depicts reflections within the water council and their collaborating organizations on how to decide on restoration as a strategy and how investments can be shared.

Discussion and conclusions

Our results show that the studied lakes will potentially experience similar climate change-related effects which will amplify issues like eutrophication and biodiversity changes, already monitored by local stakeholders. In all three cases, technological solutions have been subsequently sought to dampen climate-related issues.

Hydrological alterations such as damming have been used since many decades at lake Dümmer and remain the main solution proposed to dampen the probable decrease in water level; stakeholders at Lake St-Charles are proposing improved wastewater management through the modernisation or junction of the existing system; and several technical solutions such as biomanipulation and waste water treatment were implemented to reinforce the clear water state at Lake Ringsjön. The observed STE systems showed governance systems of which not all could effectively support system resilience. It seems they would not prove resilient if climate change-related effects are to be particularly strong. Signs of social learning in cross-sectoral platforms and participatory processes are observed in the Lake Ringsjön and Lac Saint-Charles cases and seem to transform their governance systems, bringing them closer to a practice of adaptive governance.

By comparing the three cases, we highlight the capacity of the technical, ecological and social elements within an aquatic STE system to absorb and persist when faced with outside influences and the ability of the governance system in place to adapt so that the STE system can continue to function, thus ensuring system resilience.

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Governance systems
[Building STE system resilience through Institutions & Governance: Reflections from theory and practice)

Resilience and transboundary governance in South Asia

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Summary (10 pt Arial Bold)
Transboundary river systems are some of the most appropriate avenues to foster such actions and alliances and help build the evidence base on ways resilience dividend could be achieved through regional cooperation. India, Nepal and Bangladesh annually face widespread losses across riverine, coastal and mountainous communities, and disrupted essential services in areas, constituting environments of extensive risk. Transboundary governance approaches can be developed and built through a culture of sharing, learning and trust across policymakers and practitioners in the region. There are several instances of interdependencies due to shared boundaries and sharing of resources, but a cohesive environment of trust, knowledge and expertise-sharing is lacking in how these nations individually respond and react to emerging disaster risks.

Keywords

transboundary governance; resilience; systems thinking

Introduction
Transboundary river systems are some of the most appropriate avenues to foster such actions and alliances and help build the evidence base on ways resilience dividend could be achieved through regional cooperation. Comparative studies of transboundary governance and policies to guide international disaster management can offer insights on building socio-technical resilience in the Global South. This study describes three case studies in South Asia, namely in India, Nepal and Bangladesh. These disasters have resulted in widespread losses across riverine, coastal and mountainous communities, and disrupted essential services in areas, constituting environments of extensive risk. Transboundary agreements with these three nations focus on water management practices and early warning systems. The policy response to disasters in India was put into action in 2005 by Disaster Management Act, while Nepal and Bangladesh followed the Sendai Framework of Disaster Risk Reduction, by instituting Disaster Management Acts in 2017 and 2012 respectively.

Methods: We undertook a comparative policy analysis of three case studies: humanitarian response to floods and cyclone in Eastern India, Nepal and Bangladesh. This provides insights into system response and recovery, dynamic interdependencies and complexities of disaster response systems in ongoing and recurring disasters. We rely on reflexive accounts by authors of having worked in these regions, collaborated with in-depth interviews and expert interviews to understand governance context, content and design of national policies, and roles and responsibilities of different stakeholders within these regions.

Results: There is a need to forge institutional links with other institutional frameworks such as the Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) and other regional and sub-regional cooperation mechanisms, including those related to trade and investments to initiate integrated resilience planning and implementation in the shared basins[1]. Although all three nations face annual episodes of several hazards, namely floods causing huge loss of lives and properties interventions and transboundary approaches have largely focused on early warning systems and water-sharing agreements. There are other avenues of interdependencies, which remain neglected such as coping strategies of communities. Such regional resilience building requires coordinated efforts through basin level multi-stakeholder partnerships. Unlike the current relationships dominated by central governments, this would include local communities, civil society groups, sub-national, provincial and city governments, the private sector, as well as researchers and academics.

Across the three case studies, there have been several proactive measures and policy approaches for disaster response and service delivery. These have been effective in the short-term to save lives, restore disrupted systems and allow for redundancies for communities.[2] There are institutional differences in how these policies are put in action, and how different departments and actors need to be enlisted for support for systems resilience. Longer-term development and resilience is hindered by legacies of the protection and mitigation strategies such as construction of embankments or relocation and ad hoc response by institutions for disaster risk reduction, which are marred by resource shortages, limited human resources and capacities, as well as temporary infrastructures that became permanent over the course of time. Water and river basin management are often delinked from trade and investments which are, in turn, delinked from infrastructure development, climate change adaptation and mitigation and poverty alleviation. This type of approach, which addresses issues in silos without understanding the effect on other priorities, will not be able to effectively address such complex, inter-linked and multi-dimensional challenges.

Conclusions: Transboundary governance approaches can be developed and built through a culture of sharing, learning and trust across policymakers and practitioners in the region. There are several instances of interdependencies due to shared boundaries and sharing of resources, but a cohesive environment of trust, knowledge and expertise-sharing is lacking in how these nations individually respond and react to emerging disaster risks.

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RESILIENCE AGAINST EPIDEMICS

TRACK E

Synergies and drawbacks of applying Green Infrastructure to increase resilience against epidemics

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Summary
Green infrastructure (GI) in urban environments has the potential to increase resilience against epidemics, that goes beyond creating physical barriers to separate people at safe distances. However, potential drawbacks exist as well. This paper synthesizes the synergies, drawbacks, and unknown factors when applying GI to increase resilience against epidemics. Moreover, as local experts in disaster management we reflect on the feasibility of implementing GI for this purpose in different areas around the world. Results show that GI is already being implemented to reach various goals, including increasing resilience against hazards. Successfully extending these goals to include epidemic resilience would require funding more than stakeholder acceptance, as well as considering trade-offs with other potential epidemics.

Keywords
Green Infrastructure; Epidemics; Resilience

Introduction
Different types of GI (green roofs, green walls, ground-based vegetation, porous pavement, rainwater harvesting, retention areas, waterbodies[1], etc.) have their own combination of possible synergies and drawbacks to increase resilience to hazards such as epidemics. We find that most of the pros and cons of GI to increase resilience against epidemics rely on public access, e.g. green roofs or retention areas are often restricted. Another limiting factor is existing structures vs. new structures. Given reduced costs, existing zoning law restrictions, required stakeholder consensus, and the urgency to adapt public spaces to the current pandemic, we expect it is more likely that existing GI are adapted as opposed to entirely new GI being constructed. The following GI can help increase resilience against epidemics:

- Parks (e.g. community gardens, forests, urban parks, botanical gardens, zoos, cemeteries, institutional green spaces, green sports facilities, camping areas, schoolgrounds, playgrounds, street green, canal and riverbank greens[2]) designed to give people ample walking/sitting/recreation space from each other by means of one way walking paths or the amount of space between walking paths.
- Green/blue retention areas, ponds, waterways, fountains, street trees, hedges or other vegetation, temporary planters and rocks placed in order to create space or barriers between existing traffic routes.
- Other areas with plant life e.g. green roofs/walls.

Figure 1: Examples of GI to stimulate social distancing by means of interspaced temporary and movable barriers (left) and one way walking routes (right)[3]

Table 1: Overview of potential synergies, drawbacks, and unknown factors when implementing GI to increase resilience to epidemics

Synergies	Drawbacks	Unknowns
• **Physical wellbeing:** physical barriers can separate people to safe distances to prevent both touching as well as particle spread from e.g. voice use. This enables more time being spent outdoors, leading to increased movement, recreation, and sports. Plants can help filter particles from the air and contribute to reduced air pollution[4,5], which directly affects the number of people affected by COVID-19[6]. The resulting increased health leads to a higher chance of surviving diseases. • **Mental and social well-being:** GI has been found to lead to reduced depression and anxiety; recovery from stress; attention restoration; positive emotions; social interaction; social integration; and community cohesion[7]. These help foster a positive outlook and enhanced social networks to rely on and share resources. • As certain GI help reduce floods[8] and purify water[9], these GI thereby also **reduce the spread of disease though water**.	• **Density and mobility**: More space is needed for urban parks, which leads to a higher mobility[10] that in turn could lead to more dense crowds outside of the urban parks. • Plants can increase pollen and thereby **allergic reactions**[11]; causing allergic people to exhibit symptoms similar to disease and thus an increase in confusion and fear about the symptoms' origins. • Loss of known urban landscapes if existing parks are transformed (a decrease in **attachment to place and sense of belonging**, cultural and symbolic value[12]). • Transforming GI incurs **costs** which are then not invested in e.g. healthcare, education, or transportation modifications.	• If more space is needed for people when accessing GI, this could lead to either less or more **biodiversity**. • The perceived safety of surrounding areas may rise, which in turn may lead to rising property values and increased **gentrification**. • Larger parks could allow for more crimes and increased feelings of unsafety if not monitored, and **monitoring** during epidemics is limited due to the need to keep distance from others. • The **water particle spray** of fountains may increase the spread of diseases or increase particle precipitation.

Feasibility of application

Table 1 provides an overview of potential synergies, drawbacks, and unknown factors when implementing GI to increase resilience to epidemics. The unknown factors comprise effects where we could not find past or current research concluding whether this would result in a synergy or drawback.

As for implementation, the Netherlands advises 1.5m social distancing. It is expected people will not mind changes to existing parks and infrastructure to increase resilience and much prefer the chance to be outdoors. As for economic feasibility, the funding for the Dutch Climate Agreement (klimaatakkoord[13]) to fulfil the Paris agreement can be applied to adapt existing parks or place temporary or movable GI as barriers, because most types of GI simultaneously contribute to the agreement's targets. The €566 million national compensation to local organizations (municipalities, provinces, and water boards) for Covid-19 measures does not cover adapting the urban landscape[14]. Certain municipalities might consider implementing GI to increase resilience against epidemics but the financial capacity will vary locally. A national suggested guideline with workable examples and targeted financing would increase implementation.

In the USA, social distancing guidelines are 1.8m, though the adherence to COVID-19 guidelines varies. The Centers for Disease Control (CDC) promotes staying physically active to keep the mind and body healthy, and to use parks, trails, and open spaces as a way to relieve stress, get some fresh air, and stay active[15]. The challenges to implementing GI include lack of funding, limited resources for maintenance, and competing priorities. An effective way to promote GI is through revisiting the existing plans, which oftentimes already have proposed GI projects. Another way is to find co-benefits such as promoting the GI projects that also address other threats, such as climate change. GI projects that address flooding impacts could be considered.

In Bangladesh, people are advised to maintain 1m social distancing, by contrast, delayed public campaigns and distributed coronavirus information through different media since the early March 2020 when COVID-19 started outbreaking. Mainstreaming GI to combat against multifarious epidemics (e.g., dengue) in Bangladesh is very challenging due to a number of socioeconomic and sociopolitical constraints. Nevertheless, in urban areas of Bangladesh, especially in Dhaka, the concept of 'Green corridors' as a part of GI is implemented to lessen the damages from severe flooding and storm-water management. Over last several years, people in urban areas have been encouraged to practice rooftop gardening and agriculture. However, these places became the breeding place of a decade long dengue epidemic. Thus, people in urban areas are showing less interest for said practices, both for rooftops and public parks.

In Pakistan, the government recommends maintaining a distance of 1.8m between individuals[16]. Recently, the government's reforestation initiative that aims to plant 10 billion trees across the country[17] has partnered with urban horticulture authorities to create urban forests and GI. The main objectives are tied to climate change impact mitigation, sustainable forest development, improvement in biodiversity, reducing pressures on urban drainage infrastructure, and urban flood mitigation. Lahore, Karachi, and Islamabad have existing parks and horticulture authorities responsible for GI development and maintenance. Guidelines can be issued to raise awareness and encourage adoption by e.g. sports facilities, educational institutions, banks, and hospitals, to use GI to maintain social distancing measures. The annual budget of the Parks and Horticulture Authority in Lahore is in the order of $10s millions. However, since measures countering the current pandemic have been enforced, budgets for new developments are limited. Public acceptance is likely to be inversely proportional to the inconveniences caused by the proposed interventions.

Discussion and conclusions

Even if we apply GI in such a way that it increases people's resilience against epidemics, it may not automatically be a success. People may still fear going outside and being exposed to others or viruses, even though GI is transformed to create 1.5 or 2m spaced zones. People may also be unable to use or access the GI due to physical disabilities, especially when people are (potentially) affected by a disease and need to isolate or be hospitalized. Nevertheless, GI can help play a prominent role in creating safe outdoor environments in the countries examined. We expect the main drawbacks center on costs rather than stakeholder acceptance to change. The Bangladesh case shows the importance of considering the nature of spread of potential epidemics when applying GI.

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