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Resilience in Sociotechnical Systems: The Perspectives of Multiple Stakeholders

Abstract We often design sociotechnical systems with the explicit intention that they will exhibit “resilience” in the face of unpredictable change. But there is often great uncertainty about how to define resilience – or achieve it. This article explores what design can learn about resilience by eliciting, combining, and contrasting multiple stakeholder perspectives within a single sociotechnical system. During one-on-one interviews, we asked participants to structure their ideas about resilience into a map of the overall system they work within. The maps were then used to analyze the system according to three key resilience characteristics. We found that the nature of their viewpoints was influenced by their ideas about the system’s boundaries, purpose, and timescale. Our findings give rise to a better understanding of the nature of change in sociotechnical systems and how to design for their resilience.

Keywords
Resilience
Sociotechnical systems
Stakeholder perspectives
Design communication
System change

Received June 18, 2017
Accepted October 25, 2017

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http://www.journals.elsevier.com/she-ji-the-journal-of-design-economics-and-innovation
https://doi.org/10.1016/j.sheji.2017.10.011

Introduction

Interest in the design challenges associated with sociotechnical systems has surged among design practitioners and academics in recent years.[1] Sociotechnical systems are often large and complex – public service, healthcare, and transportation, for example – and often span the boundaries dividing domains. Their success depends on interactions between technical and social subsystems, and thus a systems approach will reveal more about their structure and behavior than would examining the technical aspects or the human aspects alone.

If you asked any stakeholder in a sociotechnical system if they want that system to survive and thrive in times of uncertainty and change, they would undoubtedly say, "Yes!" But articulating what the characteristics of a resilient system are is difficult – let alone determining how that system could be better designed. This is true not only because resilience is defined differently in different domains. It is also linked to another set of concepts – including robustness, recovery, and adaptability – that are often poorly defined.

The systems we want to be strong, yet flexible, are most often complex, with interconnected subsystems that are both technical and social in nature. Even if we might be able to model and predict the behavior of a single technical or social subsystem, it is normally not possible to accurately predict the behavior of the sociotechnical system as a whole – not with the level of precision we seek. In addition, sociotechnical systems often have multiple stakeholders who have different perspectives on what the system's essential purpose and structure is. For all these reasons, if we want to design better systems, we need a systems design approach.

To achieve an understanding of resilience in design practice, we elicited feedback from multiple stakeholders in a single sociotechnical system: a development and infrastructure project at a leading European university. This involved a series of one-to-one interviews, each of which included a system mapping exercise. The mapping exercise served to structure their ideas about the system and its resilience. This article reports the findings from that study, and explores what we can learn about resilience by eliciting, combining, and contrasting multiple stakeholder perspectives within a single sociotechnical system. This research provides some understanding of how to frame individual stakeholders' perspectives on resilience within the same sociotechnical system. We hope that this will help those designing sociotechnical systems to more effectively engage with relevant stakeholders, structuring those engagements in a way that explores the many concepts that collectively define resilience.

Literature Review

In order to develop a framework for our conversations about resilience with the stakeholder participants, we first looked across the literature to identify a) the core characteristics of resilience, and b) proven approaches to a study of complex sociotechnical systems.

Resilience across Domains

Our definition of word *resilience* originates from C. S. Holling's work with ecological and socio-ecological systems, where he defines it as the persistence of system relationships and the ability of a system to absorb external changes.[2] Engineered systems are designed to reliably perform specific tasks with predictable external influences, but ecological systems must persist when confronting extreme change and uncertainty despite that lack of stability.[3] In the ecological resilience literature, systems that change over time are described using the adaptive cycle model.[4] Continuous cycles of change happen at different levels within a system – change at one

[1] Donald A. Norman and Pieter Jan Stappers, "DesignX: Complex Sociotechnical Systems," *She Ji: The Journal of Design, Economics, and Innovation* 1, no. 2 (2015): 83–106, DOI: https://doi.org/10.1016/j.sheji.2016.01.002.

[2] Crawford S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics* 4, no. 1 (1973): 1–23, DOI: https://doi.org/10.1146/annurev.es.04.110173.000245.

[3] Crawford S. Holling, "Engineering Resilience versus Ecological Resilience," in *Engineering Within Ecological Constraints*, ed. Peter C. Schulze (Washington, DC: National Academy Press, 1996), 31–43.

[4] Lance H. Gunderson and Crawford S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington: Island Press, 2001).

level influences change at another level. Over time, scholars began to apply this definition to social and socio-ecological systems.[5] As the use of the word resilience spread in academic theory, the word also gained traction in public discourse as a more general term describing survival in the face of uncertainty and change. As a result of both these trends, today the notion of resilience is widely used in many other domains, including disaster management,[6] community studies,[7] economics,[8] and psychology.[9]

Alongside this expanded range of application a set of ideas has emerged about how systems can – or cannot – respond to external influences over their lifespans. Although descriptions of resilience vary, there are three main characteristics of resilience that we will use to structure our discussion:

- R1 – Resilience as resisting influences
- R2 – Resilience as recovering from influences
- R3 – Resilience as changing to accommodate influences

When researchers in different domains define resilience, they may only refer to a subset of the above characteristics, as shown in Table 1. In this article, we view resilience as an overarching concept and a resilient system as one exhibiting all three of these characteristics – whether at different times in the system's lifecycle or across different scales.

The quoted passages in Table 1 show that the emphasis placed on certain resilience characteristics varies according to the field of study, perhaps due to differences in a system's purpose or identity. Rhan Bhamra and his colleagues compiled a list of resilience definitions across domains that highlights these differences.[10] Authors generally consider the purpose of ecological systems to be the preservation of living organisms, while they see the purpose of engineering systems as the fulfillment of specific, clearly defined tasks. Holling describes this difference clearly.

Table 1. Examples of how definitions of resilience in different fields relate to the three characteristics of resilience.

	R1		**R2**	**R3**	
	Prevention	**Impact minimization**	**Recovery**	**Incremental change**	**Adaptability**
Societal resilience[i]	"Resistance and maintenance"			"Change at the margins"	"Openness and adaptability"
Seismic resilience[ii]	"Reduced failure probabilities"	"Reduced consequences from failures"	"Reduced time to recovery"		
Supply chain resilience[iii]	"Readiness"		"Recovery"		"Response"
Engineering resilience[iv]	"The ability to prevent something bad from happening"	"The ability to prevent something bad from becoming worse"	"The ability to recover from something bad once it has happened"		

i Stephen R. Dovers and John W. Handmer, "Uncertainty, Sustainability and Change," *Global Environmental Change* 2, no. 4 (1992): 270, DOI: https://doi.org/10.1016/0959-3780(92)90044-8.

ii Michel Bruneau et al., "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities," *Earthquake Spectra* 19, no. 4 (2003): 736, DOI: https://doi.org/10.1193/1.1623497.

iii Serhiy Y. Ponomarov and Mary C. Holcomb, "Understanding the Concept of Supply Chain Resilience," *The International Journal of Logistics Management* 20, no. 1 (2009): 135, DOI: https://doi.org/10.1108/09574090910954873.

iv Ron Westrum, "A Typology of Resilience Situations," in *Resilience Engineering: Concepts and Precepts*, ed. Erik Hollnagel, David D. Woods, and Nancy Leveson (Farnham: Ashgate Publishing, Ltd., 2006), 59.

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[5] W. Neil Adger, "Social and Ecological Resilience: Are They Related?," *Progress in Human Geography* 24, no. 3 (2000): 347–64, DOI: https://doi.org/10.1191/030913200701540465.

[6] Kristen MacAskill and Peter Guthrie, "Multiple Interpretations of Resilience in Disaster Risk Management," *Procedia Economics and Finance* 18, (2014): 667–74, DOI: https://doi.org/10.1016/S2212-5671(14)00989-7.

[7] Joon Sang Baek, Anna Meroni, and Ezio Manzini, "A Socio-Technical Approach to Design for Community Resilience: A Framework for Analysis and Design Goal Forming," *Design Studies* 40 (September 2015): 60–84, DOI: https://doi.org/10.1016/j.destud.2015.06.004.

[8] James Simmie and Ron Martin, "The Economic Resilience of Regions: Towards an Evolutionary Approach," *Cambridge Journal of Regions, Economy and Society* 3, no. 1 (2010): 27–43, DOI: https://doi.org/10.1093/cjres/rsp029.

[9] Judith Johnson et al., "Resilience to Emotional Distress in Response to Failure, Error or Mistakes: A Systematic Review," *Clinical*

> "One definition focuses on efficiency, constancy, and predictability – all attributes at the core of engineers' desire for fail-safe design. The other focuses on persistence, change, and unpredictability – all attributes embraced and celebrated by biologists with an evolutionary perspective."[11]

The differences between perspectives are thought provoking. Disaster and risk management scholars and professionals, for example, focus on studying high impact, one-off events like earthquakes. For every hour that important parts of a system – such as a city – are unable to function, people suffer and money is lost. Therefore, the conceptual emphasis in the field is placed on recovery and mitigation of future influences. Resilience is

> "the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future [disasters]."[12]

The literature demonstrated that the concerns of a given domain affect its notion of what resilience is. For example, organizational resilience is defined in terms of increasing productivity and minimizing variability, while psychological resilience is defined in terms of increasing an individual's capacity to bounce back in the wake of adversity.[13]

Unifying domain-specific definitions of resilience is important, however, because in practice the resilience of any one system is affected – and, to some extent, determined – by the other kinds of systems it interacts with. Such interactions happen across domains, so resilience shown by one system has the potential to impact the resilience of another system negatively – a thriving social community can have a negative impact on an environmental ecosystem, for example.[14] The structure of a system can also be seen at different scales (e.g., timescales or spatial scales), with interactions happening across those scales, and with the resilience at one scale influencing resilience at another scale.[15]

Resilience in Sociotechnical Systems

The importance of a holistic approach to resilience is evident in the ecological and socio-ecological literature. Here we make the case that the same is true of sociotechnical systems. At a low level, technical systems should be predictable, reliable, and robust. For example, a car is designed to perform under a set of environmental conditions – temperature, road surface, and impact force, for example – each of which has a predetermined range of expected values that the car can accommodate. A car is designed to be efficient and cost effective, not to be resilient. However, when a car is combined with a driver, the combined "car-and-driver" system show resilience in the face of unexpected external events. In this combined system, the car contributes the first primary characteristic of resilience, resistance, and the driver contributes the third – an ability to change to accommodate influences. Engineers are generally adept at designing systems that resist or recover in response to influences, whereas designing systems that change to accommodate influences presents the greatest challenge.[16] Some researchers have tried to address the challenge of designing technical systems that can accommodate changing conditions and found it necessary to take a sociotechnical approach.[17]

Some researchers insist that technical systems designers and engineers have a moral obligation to consider the wider social systems that they design for or within.[18] More generally in systems engineering, by expanding the boundaries of the technical systems we consider, most designed or engineered systems either contain or interact with a variety of people, organizations, economies, and other

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***Psychology Review* 52 (March 2017): 19–42, DOI: https://doi.org/10.1016/j.cpr.2016.11.007.**

[10] Ran Bhamra, Samir Dani, and Kevin Burnard, "Resilience: The Concept, a Literature Review and Future Directions," *International Journal of Production Research* 49, no. 18 (2011): 5375–93, DOI: https://doi.org/10.1080/00207543.2011.563826.

[11] Holling, "Engineering Resilience versus Ecological Resilience," 33.

[12] Bruneau et al., "Seismic Resilience of Communities," 735.

[13] Nick McDonald, "Organisational Resilience and Industrial Risk," in *Resilience Engineering: Concepts and Precepts*, ed. Erik Hollnagel, David D. Woods, and Nancy Leveson (Farnham: Ashgate Publishing, 2006), 155–82; Fred Luthans, Gretchen R. Vogelgesang, and Paul B. Lester, "Developing the Psychological Capital of Resiliency," *Human Resource Development Review* 5, no. 1 (2006): 25–44, DOI: https://doi.org/10.1177/1534484305285335.

[14] Adger, "Social and Ecological Resilience," 347–64.

[15] David D. Woods, "Essential Characteristics of Resilience", in *Resilience Engineering: Concepts and Precepts*, ed. Erik Hollnagel, David D. Woods, and Nancy Leveson (Farnham: Ashgate Publishing, 2006), 21–34.

[16] Eloise Taysom and Nathan Crilly, "Diagrammatic Representation of System Lifecycle Properties," in *Proceedings of the 4th International Engineering Systems Symposium (CESUN)* (Hoboken: Stevens Institute of Technology, 2014): 8–11.

[17] Yeshambel Melese, Rob Stikkelman, and Paulien Herder, "A Socio-Technical Perspective to Flexible Design of Energy Infrastructure Systems," in *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (IEEE, 2016): 004669–74, DOI: https://doi.org/10.1109/SMC.2016.7844968.

[18] Pieter Vermaas et al., *A Philosophy of Technology: From Technical Artefacts to Sociotechnical Systems* (San Francisco: Morgan & Claypool Publishers, 2011).

entities that are often best understood on a sociotechnical basis.[19]

The sociotechnical systems that stakeholders must analyze, understand, and improve are often partially designed and partially evolved.[20] This requires stakeholders to grapple with system complexity that they only partly understand, and interpret emergent behavior that was not anticipated.[21] The function and structure of such systems is perspective dependent – in other words, two stakeholders might each view the function and structure of the system from different perspectives. The perspectives that stakeholders adopt can be determined by where they draw the system boundary, what entities they attend to within and beyond that boundary, the details they perceive in those entities and the scales that they are considering (e.g., timescales and spatial scales). We refer to all this as the stakeholders' "level of abstraction," as their view of any given part of the system (both its structure and its function) can be more or less abstract depending on a range of different factors, including their domain knowledge and their roles and responsibilities with respect to the system. In sociotechnical systems theory, systems are grouped into three types: primary work systems, for example subsystems of an organization; whole organization systems; and macrosocial systems, such as national institutions.[22] In this study, we use a similar approach to understand the resilience of a sociotechnical system, combining individual stakeholder perspectives on different types of system at different levels of abstraction.

Research Methodology

The study was designed as a series of in-depth interviews with stakeholders all working in the same system: a €1 billion urban campus development project initiated and managed by a leading European university. This initiative was designed to provide affordable housing for university staff and postgraduate students, and provide a place to foster university research. Over the long term, the goal was to enhance the university and city.

The term "resilience" was used in project reports relating to both technical systems (such as buildings) and social systems (such as communities). For example, in the development documentation and news articles, there are references to designing in adaptive measures that will ensure resilience in the face of climate change, and planning resilient neighborhoods that will be future proof for hundreds of years.

We conducted our one-on-one interviews between March and August 2016. At that point, 75% of the "phase one" development had been built, but no residents had moved in. Further phases of development, to extend the site, were planned – developers expected the building stage of the project to take 15 years in total. We have withheld further details of the development – including its location and the organizations involved – to protect the anonymity of the participants in this study.

Sample

We interviewed eleven people working in several domains and in different organizations (Table 2) so that there was a greater breadth of both social and technical systems discussed. We used the participants' job roles to determine the levels of abstraction that they were likely to view the system from – for example, S2 primarily talked about people and communities, whereas S3 primarily talked about buildings and infrastructure. We identified relevant stakeholders through a combination of direct contact and chain referral sampling.[23]

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[19] Peter Kroes, Maarten Franssen, Ibo van de Poel, and Maarten Ottens, "Treating Socio-Technical Systems as Engineering Systems: Some Conceptual Problems," *Systems Research and Behavioral Science* 23, no. 6 (2006): 803–14, DOI: https://doi.org/10.1002/sres.703.

[20] Olivier L. de Weck, Daniel Roos, and Christopher L. Magee, *Engineering Systems: Meeting Human Needs in a Complex Technological World* (Cambridge, MA: MIT Press, 2011).

[21] Regina Frei and Giovanna Di Marzo Serugendo, "Concepts in Complexity Engineering", *International Journal of Bio-Inspired Computation* 3, no. 2 (2011): 123–39, DOI: https://doi.org/10.1504/IJBIC.2011.039911; Regina Frei and Giovanna Di Marzo Serugendo, "Advances in Complexity Engineering", *International Journal of Bio-Inspired Computation* 3, no. 4 (2011): 199–212, DOI: https://doi.org/10.1504/IJBIC.2011.041144; Chih-Chun Chen and Nathan Crilly, "Describing Complex Design Practices with a Cross-Domain Framework: Learning from Synthetic Biology and Swarm Robotics," *Research in Engineering Design* 27, no. 3 (2016): 291–305, DOI: https://doi.org/10.1007/s00163-016-0219-2; Chih-Chun Chen and Nathan Crilly, "From Modularity to Emergence: A Primer on the Design and Science of Complex Systems," accessed November 5, 2017, http://complexityprimer.eng.cam.ac.uk/.

[22] Eric L. Trist, *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program*, Issues in the Quality of Working Life: A Series of Occasional Papers, no. 2 (Toronto: Ontario Quality of Working Life Centre, 1981).

[23] Patrick Biernacki and Dan Waldorf, "Snowball Sampling: Problems and Techniques of Chain Referral Sampling," *Sociological Methods & Research* 10, no. 2 (1981): 141–63, DOI: https://doi.org/10.1177/004912418101000205.

Table 2. **System stakeholders' job roles, organizational affiliations, and main systems of interest (as cited).**

Stakeholder ID	Job role*	Organization	System of interest
S1	Community development	Local authority	City
S2	Councillor	Local authority	City
S3	Planning	Local authority	City
S4	Academic	University	University
S5	Academic and governor	University	University
S6	Project management	University (project team)	Development
S7	Project management	University (project team)	Development
S8	Construction	University (project team)	Development
S9	Operations	University (project team)	Development
S10	Architecture	Consultant	Area**
S11	Architecture	Consultant	Area**

* As defined by the stakeholder in the interview when selecting a system boundary.
** Defined as a subsection of the development project.

Figure 1 shows the distribution of stakeholders according to their job roles. Each level shown is an organizational group. These organizations overlap, with the dotted lines delimiting the project boundaries. All of the stakeholders interviewed were directly involved in the development project.

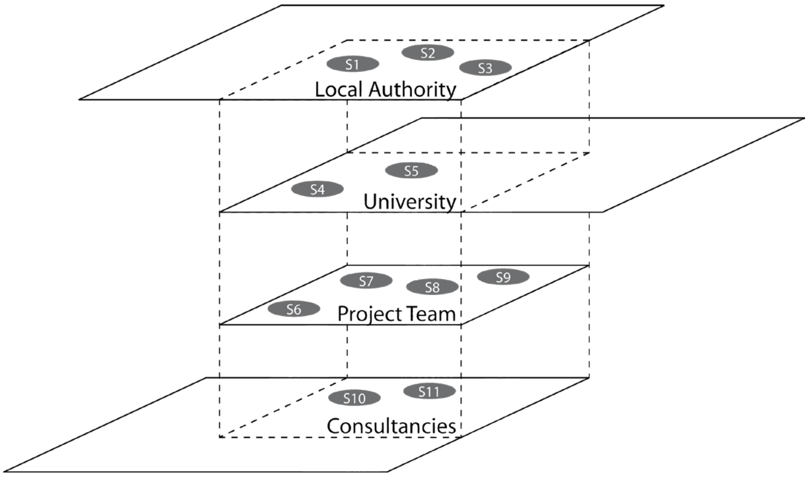

Figure 1 A schematic illustrating the distribution of the stakeholders according to the organization they worked for. The project team is employed by the university solely to implement the development project, but is treated as an independent organization. Everyone interviewed was directly involved with the development project and thus fall within the dotted lines. The local authority, university, and consultancies all have parts of their organizations that are not involved with the development project, as illustrated by the extension of the planes beyond the dotted lines. Image © 2017 Eloise Taysom.

Data Collection

The first author conducted all the interviews, which took place at the stakeholders' workplaces. The sessions lasted fifty-three minutes on average – minus the opening introductions and final wrap-up. With the participants' consent, all interviews were recorded and subsequently converted into transcripts whose total word count was over sixty thousand. The interviewer used a structured interview format to ensure all stakeholders were asked the same key questions – although the length of time spent on each question and the number of additional prompt questions varied depending on the stakeholders' answers. This meant that points of interest could be explored in more depth.[24]

The interviews had two main parts. In the first part, we asked the stakeholders questions about their job role and how it related to the development project, what resilience meant to them, and ways they might design for resilience. This part of the interview was designed to build rapport and gauge each stakeholder's initial understanding of the notion of resilience. After the first discussion, the interview moved onto the second part: a system mapping exercise.

System Mapping Exercise

In the system mapping exercise, the stakeholders were asked to choose a system boundary that reflected their main concern. For example, a stakeholder involved in running the university might think about the university as their main system, with a new development as one subsystem in the university. Other systems, such as the local authority, might be thought of as external to that main system. Conversely, a stakeholder involved in managing the city might think about the university as one subsystem of the city. Each system mapping exercise was conducted from the perspective of the individual stakeholder involved.

The mapping exercise started with a blank sheet of A3 paper. The interviewer started by explaining the exercise and drawing a large rectangle to model the system boundary. Starting the exercise this way – as opposed to having pre-printed sheets – was intended to make the exercise more approachable and reduce any possible anxiety around visual literacy.[25] Once this boundary was drawn, the stakeholders were asked to

1. Label the system boundary;
2. Write the purpose for the system specified at the top of the page;
3. Write three social systems on pink sticky notes;
4. Write three technical systems on yellow sticky notes;
5. Arrange the sticky notes and draw relationships between them;
6. Assign colored dots to each sticky note to represent the three resilience characteristics (red = resist, blue = recover, green = change);
7. Discuss examples relating to resilience and develop the system map with new additions on green sticky notes.

An example of how a stakeholder's system map was built up is shown in Figure 2. In the interviews, social systems on the pink sticky notes were referred to as "people, who could be individuals or groups of people," and technical systems on the yellow sticky notes were referred to as "things, which are any subsystems that are not people."

The stakeholders were free to draw relationships as they chose, using lines or directional arrows. We placed no constraints on what type of "thing" the subsystems had to be. For instance, the stakeholders chose to include physical entities like buildings, contractual entities like budgets, or legal contracts, and abstract entities like reputation or performance. Similarly, the "people" could be individuals, groups or organizations, as defined by the stakeholders. A sampling of the variety of system maps we obtained is shown in Figure 3.

Data Analysis

The interview transcripts – which reproduced the initial discussion and the system mapping exercise exchanges – were qualitatively coded in Atlas.ti using a pre-defined code list that had been developed from a previous research study. Although a code list was used, we expected new codes to emerge from the data during an iterative inductive process.[26] We asked a second researcher with no prior knowledge of the study to code half of the transcripts without a pre-defined code list, and the two researchers then compared themes to identify overlaps and gaps in the analysis.

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24 Michael Q. Patton, *Qualitative Evaluation and Research Methods*, 2nd ed. (Thousand Oaks: Sage Publications, 1990).

25 Anna Bagnoli, "Beyond the Standard Interview: The Use of Graphic Elicitation and Arts-Based Methods," *Qualitative Research* 9, no. 5 (2009): 547–70, DOI: https://doi.org/10.1177/1468794109343625; Nathan Crilly, Alan F. Blackwell, and P. John Clarkson, "Graphic Elicitation: Using Research Diagrams as Interview Stimuli," *Qualitative Research* 6, no. 3 (2006): 341–66, DOI: https://doi.org/10.1177/1468794106065007.

26 David R. Thomas, "A General Inductive Approach for Analyzing Qualitative Evaluation Data," *American Journal of Evaluation* 27, no. 2 (2006): 237–46, DOI: https://doi.org/10.1177/1098214005283748.

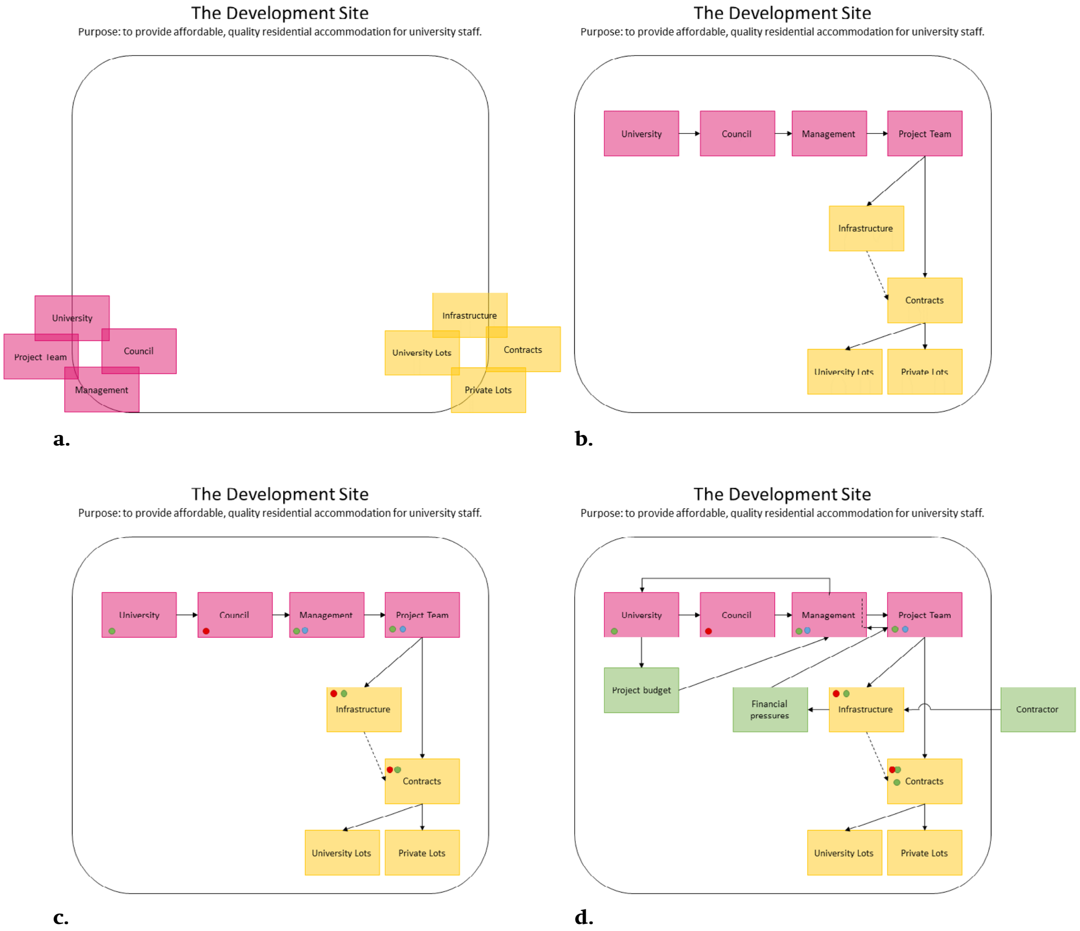


Figure 2 Four sequential stages of the system mapping exercise: (a) steps 1–4: defining a system boundary—“The Development Site” in this instance—and the system’s purpose, identifying people [pink] and things [yellow] as subsystems; (b) step 5: arranging subsystems and drawing relationships; (c) step 6: identifying resilience characteristics for each subsystem; (d) step 7: exploring and developing the system map based on further discussion [additions in green]. Image © 2017 Eloise Taysom.

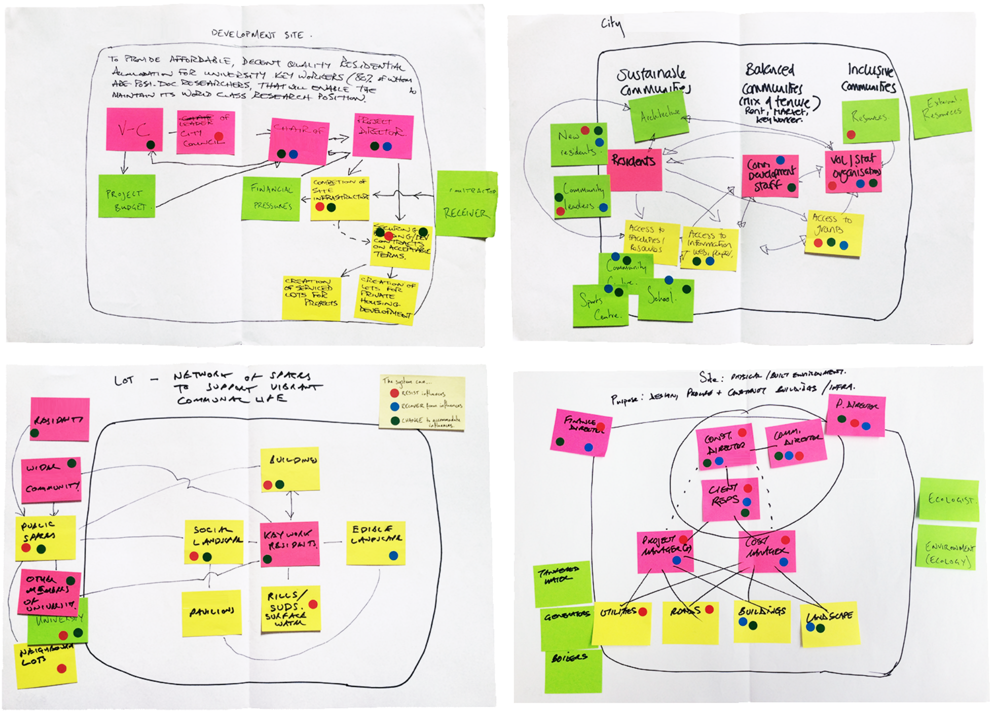


Figure 3 Four stakeholders’ completed system diagrams. Image © 2017 Eloise Taysom.

Findings

The study was deliberately designed to gather a range of stakeholder perspectives across domain boundaries and levels of abstraction. The level of abstraction of each stakeholder was indeed an important factor in how each stakeholder viewed resilience, represented by how they identified *system boundary and purpose*. The second main factor that influenced the stakeholders' perspectives was *system timescale*. This was not predefined in the system mapping exercise – perceptions of the system timescale varied between participants. Stakeholders' perceptions of the timescale had a large impact on how they discussed resilience.

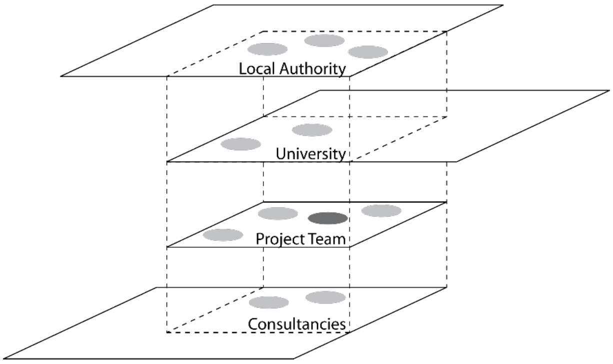
System Boundary and Purpose

During the mapping exercise, the stakeholders first defined a system boundary – their main system of interest – and then defined a purpose for that boundary. Four systems were identified: the city, the university, the development site, and smaller physical areas of the development site. The purposes that the stakeholders assigned to these systems can be seen in Table 3.

Table 3. System boundaries and purposes as defined by the stakeholders.

Stakeholder ID	System boundary	Purpose
S1	City	To provide sustainable, balanced, inclusive communities.
S2	City	To retain the city's existing character, including preserved countryside and transport links.
S3	City	To provide affordable housing.
S4	University	To support a world-class academic environment which can continue to excel on a global scale.
S5	University	To maintain research outputs of ideas and people.
S6	Development	To provide affordable, quality accommodation for university staff, which will enable the university to maintain its world-class status.
S7	Development	To maintain the university's global competitiveness over the next time horizon.
S8	Development	To design, procure, and construct buildings and infrastructure.
S9	Development	To develop and deliver a world-class, sector-leading, mixed-use development for the university.
S10	Site area	To provide design coordination.
S11	Site area	To provide a network of spaces to support communal life.

The list of purposes in Table 3 shows that the stakeholder's definition of purpose is dependent on their system of interest and their perspective on that system. The two stakeholders leading the project team (S6 and S7) – who both defined the development site as their system boundary – defined the purpose of the site in the context of the university's overall goal, to maintain competitiveness. Conversely, those in more specific roles considered the development at a different level of abstraction. For example, the construction stakeholder (S8) established the development site as the system boundary but identified the purpose of the system as the production of buildings and infrastructure (Figure 4). In practice, system boundaries and purposes were framed by the professional role of the stakeholder and the people and things they interact with on a day-to-day basis.



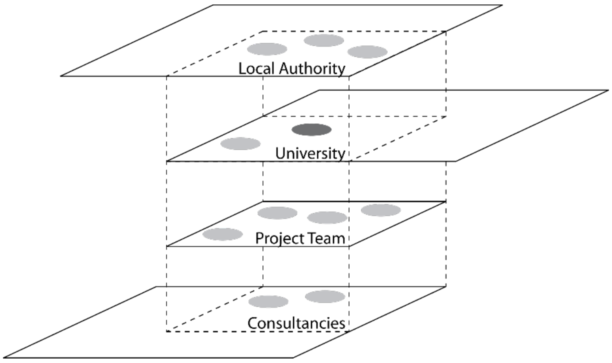


Figure 4 (Left) Stakeholder S8's position in the system (darker dot) relative to the other stakeholders. Image © 2017 Eloise Taysom.

Figure 5 (Right) Stakeholder S5's position in the system (darker dot) relative to the other stakeholders. Image © 2017 Eloise Taysom.

> "I'm responsible for design, procurement, and construction.... I interact very closely with the rest of the project team and I have to make sure they can operate effectively in the same sphere but they're not involved day-to-day in terms of design, procurement, and construction of the buildings." – S8

The differences in purpose may seem trivial, but these boundaries and purposes determined what the stakeholders identified as being most important in the system. For example, stakeholder S6 included social systems involved in governance – university governance, the local authority, and the project team – whereas stakeholder S8 included social systems from the project team level down to managers of utilities, roads, and buildings. Both defining a system boundary and defining a system purpose are important because the former broadly frames the problem and the latter points to the types of social and technical subsystems a stakeholder has in his or her view. It is only by making these factors explicit that we can understand how stakeholders perceive resilience. This can be seen in the discussion with stakeholder S5, who defined the system's boundary as the university, and its purpose as maintaining the university's research output (Figure 5). When asked to relate this purpose to resilience the response was

> "Whatever kind of institution we are in fifty years, this development will add to the strength of the university because [the development is] a fantastic resource – either for places to live, for places to work or as a source of income. It really doesn't matter. In any of those modes, it's making the university more resilient." – S5

This contrasts with the project teams' goal of providing affordable accommodation, which has implications for the design of the buildings on the development. For a project manager, cost is a major driver, but for the stakeholders operating at the university level (S4 and S5), the legacy of the buildings was deemed more important than their initial function. One stakeholder described this by comparing the new development buildings to an old university building in the city that is still in use.

> "For an older building, although you might gut the inside, the essential features that make it beautiful are not changed. The [old university building] is a good example. It's a beautiful, beautiful building from the outside and it has been mucked about on the inside to make it functional, but its real resilience is that they haven't been allowed to rip it apart. In the development, the buildings that are being designed are quite flexible, but they will be unable to retain their essential character when they're subject to change." – S4

This idea of retaining an "essential character" was reiterated by other stakeholders. For example, stakeholder S2 – who was most interested in the resilience of the city – said

> "I think that cities are rather like human beings: they have intrinsic value and

> intrinsic worth. They don't have to be justified by what they do or what they aim to do." – S2

For complex systems, such as universities and cities, purpose is subjective and multifaceted. When a stakeholder has a clear goal or contract, a system's purpose can be defined in terms of technical systems or outcomes. For example, the project team is ultimately responsible for delivering a technical system – the development buildings and infrastructure – by following a plan and adhering to a budget. However, many of the stakeholders were trying to articulate a purpose that was a combination of social and technical systems, with goals that are hard to measure. One architect described this in terms of selling a dream.

> "So part of what we do is comply with these technical requirements, but also we sell dreams." – S10

This balance between higher level "dreams" and the delivery of technical systems means that many stakeholders described themselves as thinking at different levels of abstraction within (and beyond) the system boundary they had defined in the map. The architect quoted above described the process.

> "It's going from the micro to the macro. So at one level you're working on town planning, and then you zoom in a little bit more and you're looking at how you mitigate the impact of lorry deliveries. So that's what we do – constantly move between the two scales, so you have to have a bit of an idea about where you're heading to, and the detail to inform the more fluid, fluffy things." – S10

Another stakeholder described how they had chosen a certain "lens" to draw their system map but they could have chosen another, which would mean discussing the system at a different level of abstraction. It is possible for a single stakeholder to be concerned with multiple system boundaries; by definition, the boundary that they choose will influence their definition of purpose. Whilst these multiple lenses might reflect different levels of abstraction – from overall vision to implementation details – there can also be multiple lenses that reflect the system, or the stakeholder, at different points in time.

System Timescale

System timeframe was a major factor that influenced stakeholders' perspectives. Each stakeholder thought about the development relative to a timescale that was largely defined by their job role, but was also affected by other parameters that were harder to define – including personal values and domain outlook. For example, one stakeholder's job required short-term involvement in the planning of a development, but part of that planning included thinking ahead to how the finished development would operate. In addition, that stakeholder also lived in the city and was concerned about the impact of the development on the city in the long term. This stakeholder's perspective on timescale covered an extended period, although the stance they took on the system at any one time could be with respect to either the development as a plan or the development as a place. In this way, all of the stakeholders' perspectives on the system timescale were layered and multifaceted. The relationship between time and perspective was also interdependent; the timescale the stakeholders thought about affected their perspectives, and their perspectives affected the timescale they thought about.

In the system mapping exercise, the stakeholders were required to define a system boundary and purpose, which delimited the timescale that was discussed. For example, both architects defined their system boundary as an area on the development. One of these architects, S10, defined the purpose in terms of "design coordination," which is the purpose of the architectural firm itself. This meant that the people and things identified in the system map were related to the development as a design and implementation project – things like contractors, noise criteria, and design codes. However, the other architect (S11) framed the discussion around the development as a place, which was the product of the design process being implemented. This stakeholder said the system's purpose was "to provide a network of spaces to support communal life." Correspondingly, the systems identified on the system map were related to the development as a living environment – residents, buildings, public spaces, and the like.

Articulating and defining a system's purpose in this way was useful, because the conversation moved from a general discussion across a breadth of timescales at the start of the interview to a focused, well-defined discussion in the mapping exercise. Looking across all of the interview data, there appeared to be three distinct time periods, or "epochs,"[27] which we detail in Table 4.

Table 4. Details about the three time periods of the development: plan, process, and product.

Epoch	Description	Length of time*	Social system examples	Technical system examples
Plan	Development plans drawn up	10 years	University; local authority; city residents	Planning application; planning approval; plan
Process	Development built out	15 years	University; project team; architects	Buildings; infrastructure; utilities
Product	Development in use	60 years	University; local authority; development residents	Building; landscape; services for residents

* Rounded to the nearest 5 years.

We mapped the stakeholders to these three epochs according to what was discussed in each interview. In the map shown in Figure 6, the horizontal bars represent each stakeholder, with the darker sections indicating the timeframe that was primarily referred to in the system mapping exercise, and the lighter sections indicating other epochs discussed by the stakeholder. The dotted vertical line represents the point in time when the interviews were conducted. As might be expected, all of the stakeholders at some point talked about their system of interest as a product. This is because plans and processes are forward looking, with the product as the end goal.

All of the stakeholders were interviewed in the fourth year of the process phase of the development. This means that the plan timescale is based on what has already happened, the process timescale is based on current project plans, and the

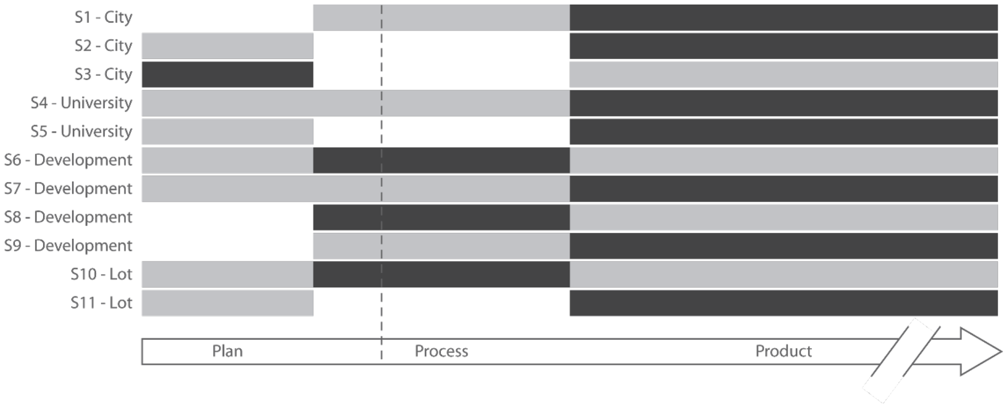


Figure 6 System timeline divided into three epochs: plan, process, and product. Stakeholders are mapped onto the timeline with horizontal bars representing the epochs that were discussed in each interview. The darkest bars represent the primary focus of the stakeholder during the system mapping exercise. Image © 2017 Eloise Taysom.

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[27] Adam M. Ross and Donna H. Rhodes, "11.1.1 Using Natural Value-Centric Time Scales for Conceptualizing System Timelines through Epoch-Era Analysis," in *INCOSE International Symposium* 18, no. 1 (2008): 1186–201, DOI: https://doi.org/10.1002/j.2334-5837.2008.tb00871.x.

product timescale is based on design practice – the architects said that they generally design buildings to last for sixty years, for example. There were a few discrepancies for the product timeline, with some stakeholders saying they thought about what the development would be like in one hundred to two hundred fifty years' time. However, an outlook of sixty years is generally representative of examples given in the interviews of the development in use.

Making distinctions between time periods is useful because they represent a marked change in the way stakeholders talked about resilience. For example, the stakeholders who span across all three epochs in Figure 6 (S4, S6, S7, and S10) were all senior stakeholders managing their respective systems. These stakeholders' job roles required them to take a long-term, high-level view. This contrasted with stakeholders who had very specific job roles and tended to focus on one epoch – S2 and S3, for example.

Resilience across Multiple Perspectives

It is important to note that time has an effect that is independent of any one perspective. Systems change over time, both in their composition and in the way they respond to influences. This means that the structures and functions that allow a system to be resilient at one point in time might be different at a future point in time. For example, one stakeholder (S7), after saying that the resilience for the development came from the university, realized that this might change in the future once the development was in use.

> "The resilience of this project comes from the university. As a place, when the development is built and operating as part of the community, I suppose the resilience will then come from the residents, and some of the organizations that are working on the ground, like the school and the community center." – S7

Although, as one stakeholder pointed out, a social system that is present across multiple epochs, in the form of a consistent stakeholder, can increase the resilience of a system.

> "I actually think most of the resilience for the development comes from the university's backing and commitment to being the long-term stakeholder, that's what sets it apart from other developments. I think you might find that other housing developments are much more fragile." – S7

Having stakeholders who are only involved for a portion of a system's lifespan can be an issue for two reasons. Firstly, a long-term stakeholder is more likely to make decisions that positively impact the future resilience of the system. Secondly, if one stakeholder takes over control from another partway through the lifetime of a system, these two stakeholders must establish an interface between them, such as a contract. Looking across epochs in the study highlighted these interfaces as important aspects of resilience across many different types of systems. Interfaces can take different forms and can be either temporal or structural, as shown in Table 5.

Table 5. Examples of structural and functional interfaces identified in social and technical systems.

	Social	**Technical**
Temporal	Legal contract between technical specialist and project team	Transition between the building planning stage and the implementation stage
Structural	Project team organizational structure	A physical interface between one area and the rest of the development

The data from the interviews also gave us an insight into how these types of systems could change. The stakeholders were asked to give examples of system change when labeling subsystems with resilience characteristics. In most cases, it was possible to identify an influence that initiated the change, and an agent that enabled the change in response to the influence – although, at times, the change agents were hard to identify. For example, in some cases the influence and change agent appeared to be the same entity; however, upon closer inspection, there appeared to be a chain of influences and agents. Stakeholder S10 described how the architects accommodated influences – in this case the client changing their mind.

> “So as we’re designing along, believe it or not, the project team changes their mind about things and we have to accommodate them.” – S10

This description suggests the project team influenced the architect and the architect adapted – in this case, the change agent is internal to the architectural firm. However, the stakeholder then continued explaining this example, saying that the area they were designing had to accommodate more apartments than initially expected, but the way they had designed that area meant that these extra apartments could be added into the design.

> “We had to accommodate additional apartments because they couldn’t fit them in another area. So our buildings got bigger, but the design proved we could accommodate those changes as we went along.” – S10

From this description, the situation looks more complicated. It seems that the design requirements for one area of the development were influenced by other areas. So the project team then made a change to the development’s design requirements – how many apartments were to fit into an area. The project team influenced the architect to accept these design changes but the changes were only possible because the design of the area was flexible enough to begin with.

It should be noted that the choice that stakeholders make about whether a system resists, recovers, or changes is also dependent on their perspective of the system. For example, in the above example, the architect said that the design was able to change. Some people could view that change as a recovery. It is not clear in this study if the stakeholders thought in much depth about the difference between a system recovering and a system changing. There was, however, some suggestion that when social systems were forced to change – when they faced a negative external influence – then that change was classed as a recovery. Whereas when social systems proactively changed – by taking advantage of a new opportunity – then this was classed as changing to accommodate influences.

For all types of system, when stakeholders were discussing systems that persisted over long periods of time, they seemed more likely to describe them as “resisting.” For example, one stakeholder contrasted two types of social systems, saying that resisting influences is an advantage for long-established organizations but that organizations operating at a lower level, on a shorter timescale, must change in response to influences.

> “I actually think that the university is relatively slow to change, but they’re very robust in themselves and that’s why they have had such longevity.... Our [project] team is a bit different. We’re not operating at a governance level; we’re operating at an executive level. We are charged with delivering something – not over hundreds of years, but over two or ten years, so our perspective is different and we need to function quite a bit more flexibly than a lot of the university.” – S7

In this case, the stakeholder works for the team running the development project, and sees the project as a part of the university, albeit with a highly specific scope of activity. Therefore, some stakeholders did not distinguish between the project team and the university and viewed the university as able to change in response to influences.

> "I think you'd have to say the university resists. Although, that being said, the university has shown a lot of foresight by opting for this development, which is a very evolutionary thing. Yes, I think actually the university can change." – S11

These differences in perspective partly depend on how closely involved stakeholders are with a certain system in their daily practice. For example, when stakeholders identified systems on their maps, they grouped together systems that had less impact on their work and broke down systems that were more significant into lower levels of detail. This has implications for assessing resilience, because a system could be incorrectly characterized by a stakeholder as unable to change in response to influences if that stakeholder is not familiar with that system's function and structure. In fact, all of the stakeholders described themselves or their team as able to change, regardless of how other stakeholders described them, suggesting that there can be small scale changes that only local stakeholders are aware of.

Resilience of a Sociotechnical System

Taking a sociotechnical approach in this study allowed us to identify and compare the resilience characteristics in social and technical systems. Across the system maps, the distribution of the systems that were labeled as R1 (resist) was equal across social and technical systems. Whereas, for R2 (recover) and R3 (change), sixty percent of the systems attributed with these characteristics were social and forty percent were technical. These distributions were reflected in the ways the stakeholders talked about social systems in contrast to technical systems. Social systems were seen as "messy" and "complicated," but they were also seen as readily able to change.

There was also a difference between social and technical systems in the type of change the participants described. In general, social systems were perceived as able to change in response to influences without outside intervention – an internal agent might facilitate the change. In contrast, for technical systems to change, they were perceived as requiring an external social system to act as a change agent. This difference in the way that social and technical systems were seen to change framed stakeholders' perspectives on how resilience can be achieved. For example, one stakeholder reasoned that resilience comes from changing stakeholder attitudes so that better decisions are made about how to design technical systems.

> "If you change people's attitudes and the facilities through which those attitudes and decisions and ambitions can be articulated, everything else flows from it. But if you start saying we should have more resilient buildings you're looking up the wrong end of the pipe." – S4

This view was reflected by nine of the eleven stakeholders interviewed. They said that social systems, rather than technical systems, contributed most to the resilience of a sociotechnical system. The technical systems were perceived as the "end product" created by social systems or the "structure" that supports social systems. Some stakeholders went so far as to say that social systems could still be resilient without resilient technical systems.

> "If the infrastructure is rubbish you could still get a sense of community, but it might be in adversity." – S1

This is in contrast to technical systems. In the only examples given where a social system proved to not be resilient, the technical systems supporting that social system were implicated as being negative influences, and the sociotechnical system as a whole was deemed to have failed. This suggests that, because stakeholders think that the purpose of technical systems is to support social systems, these technical systems can only be said to be resilient if the social systems they are designed to support are resilient.

Discussion

Focusing on the sociotechnical is an effective way to analyze resilience – and related concepts – in systems that are more conventionally approached from either a social or technical perspective, as is the case with communities and infrastructure.[28] In this study, we demonstrate that a holistic analysis of a sociotechnical system reveals new insights into the characteristics of resilience. However, we have built upon the existing literature by identifying a set of parameters that must be considered when taking a systems design approach to resilience. These include system domain, stakeholder purpose, system abstraction, and timescales. These factors must be considered from multiple stakeholder viewpoints because the way a system's resilience is defined depends on the perspective of the person looking at it.

Drawing the boundaries of the system is necessary when considering a complex system because it is impossible to look at all the elements and interconnections at once. However, any boundary that is drawn will be a compromise between being wide enough to account for different aspects of the system and narrow enough to be comprehensible.[29] Using a systemic approach to analyzing the perspectives of multiple stakeholders mitigates this issue. This study has demonstrated that the complexity and breadth of a sociotechnical system can be explored across multiple interviews whilst using manageable boundaries with individual stakeholders.

In the resilience literature, the perspectives of individual stakeholders in a sociotechnical system have not previously been explored in detail. Despite this, resilience is often defined with respect to a negative outcome or influence, such as, the "ability to prevent something bad from happening."[30] Whether an outcome or influence is bad is dependent on perspective. Therefore, for a complex sociotechnical system with many stakeholders, there will be different perspectives on what resilience means for a specific system, and whether that system is resilient or not. This study also illustrated that each stakeholder can have a localized view of a system. Therefore, different stakeholders will view the same system as having different structures, functions, and timescales, or a single stakeholder can hold more than one such perspective. This means that factors that one stakeholder might identify as increasing resilience may be viewed by another stakeholder as detrimental to system resilience. This confirms a similar finding that was observed in another study on resilience in communities.[31]

Although there is some literature that takes a sociotechnical approach to researching resilience, these studies tend to be domain-specific. To avoid domain specificity, this present study used three characteristics, which were shown to have applicability across domains. These characteristics were then applied to social and technical systems, demonstrating how social and technical systems display different resilience characteristics and the types of sociotechnical interactions that lead to resilience. This has implications for systemic design, offering an approach that can be generalized to understanding resilience in sociotechnical systems.

When resilience research began, a clear distinction was made between ecological resilience and engineering resilience, whereas social resilience was generally

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[28] **Melese et al., "A Socio-Technical Perspective," 004669–74; Baek et al., "A Socio-Technical Approach," 60–84.**

[29] **Gerald Midgely, "Systemic Intervention for Public Health," *American Journal of Public Health* 96, no. 3 (2006): 466–72, DOI: https://doi.org/10.2105/AJPH.2005.067660.**

[30] **Westrum, "A Typology of Resilience," 59.**

[31] **Baek et al., "A Socio-technical Approach," 60–84.**

seen in a similar way to ecological resilience.[32] Although the boundaries between these definitions have blurred over time, we found evidence that some stakeholders still perceive social and technical systems in a similar way. Social systems were perceived to change readily, whereas technical systems were seen as more rigid. It was clear that social systems increase the resilience of sociotechnical systems by being adaptable, and at times, technical systems limited the ability of a sociotechnical system to change even when change was desirable. However, the stakeholders in our study appeared to be using these properties to structure and control the complexity of sociotechnical systems. This was achieved through interfaces. Technical systems acted as interfaces between different social systems, as well as different points in time. These types of trade-offs between resilience characteristics are implied in some resilience studies, but they have not previously been made explicit or been related to the system parameters that we have identified here.

This research has demonstrated the importance of cross-scale interactions in sociotechnical systems, building on and extending work in the ecological and social sciences on the concept of panarchy.[33] Understanding these dimensions and relating them to resilience means that fundamental questions about resilient systems can be answered, including which systems should be resilient, according to whom, resilient relative to what, resilient over what timescale, and resilient in what way? Once these questions about a sociotechnical system are answered, then resilience characteristics can be applied to work out which parts of that system should be changeable and therefore how the system architecture should be designed.

Conclusions

Whilst many studies consider the resilience of individual systems from a specific perspective, most large sociotechnical systems are really a constellation of systems with many stakeholders each with their own – or multiple – perspectives. This study has shown that perceptions of resilience are strongly linked to individual stakeholders' perspectives, which can be framed by identifying perceived system boundaries, purposes, and timescales. New insights were found about resilience that relate to system interfaces, types of change, and interactions between social and technical systems. In particular, this furthers our understanding of stakeholder perspectives on resilience by determining the factors that influence an individual stakeholder's perspective as well as the types of findings that can be gained by using this approach. By comparing and contrasting stakeholder perspectives across a single sociotechnical system, we have shown it is possible to gain fresh insight into what makes a system resilient with respect to system domain, stakeholder purpose, system abstraction, and timescales. We have also explored similarities and differences between technical and social systems.

This study was based on a development project, but by categorizing the subsystems broadly into either "social" or "technical," and using three overarching resilience characteristics, we expect the findings to be applicable across all sociotechnical systems. This is confirmed by the consistency of our findings with other domain-specific studies. The study showed that by taking a systemic approach, we can overcome the problems of communicating with stakeholders across domains, which offers new insight into how to frame stakeholder perspectives on resilience and what these perspectives can reveal about the factors that make sociotechnical systems resilient. The methods we used to explore the viewpoints of the stakeholder participants are domain agnostic, and therefore would be applicable to any set of system stakeholders. To build on our findings, the multi-stakeholder approach adopted here could be used to explore resilience in other types of systems. We have shown that by taking a systems approach, we can overcome the problems

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[32] Holling, "Engineering Resilience versus Ecological Resilience," 31–43; Adger, "Social and Ecological Resilience," 347–64.

[33] Craig R. Allen et al., "Panarchy: Theory and Application," *Ecosystems* 17, no. 4 (2014): 578–89, DOI: https://doi.org/10.1007/s10021-013-9744-2.

of communicating with stakeholders across domains, and gain new insights into both how to frame stakeholder perspectives on resilience and what these perspectives can reveal about what makes sociotechnical systems resilient.

Acknowledgments

The authors wish to thank all of the participants in this study for their time and insights. This work was supported by the UK's Engineering and Physical Sciences Research Council (EPSRC) through a Doctoral Training Grant awarded to Eloise Taysom and an Early Career Fellowship awarded to Nathan Crilly (EP/K008196/1). The raw data from the study cannot be made freely available because inherent to that data is sensitive information relating to the individuals and organizations involved.