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# Resilience: A multi-stakeholder perspective

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# Resilience in socio-technical systems: the perspectives of multiple stakeholders

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## Abstract

Socio-technical systems are often designed with the explicit intention that those systems will exhibit 'resilience' in the face of unpredictable change. But there is often great uncertainty about what resilience really means in this context and how it can be achieved. This paper explores what can be learnt about resilience by eliciting, combining and contrasting the perspectives of multiple stakeholders of a socio-technical system. Communicating about resilience is challenging because the term means different things to different people, both within and across domains. Therefore, in this study a system mapping exercise was used with stakeholders in one-to-one interviews to structure conversations about resilience. The system maps produced with stakeholders were used to analyse the system according to three characteristics of resilience. The findings of the study draw out key themes, including the way in which stakeholders' perspectives are influenced by their ideas about system boundary, system purpose and system timescale. This gives rise to a better understanding of the nature of change in socio-technical systems and how to design for the resilience of such systems.

## Introduction

In both design literature and practice there has been increasing interest in the design challenges associated with socio-technical systems.[1] These socio-technical systems, such as governance, healthcare and transportation, are often large and complex, spanning across domain boundaries. Their success is usually dependent on the interactions between technical and social sub-systems. Therefore, taking a systemic approach to the design of socio-technical systems can reveal insights about their structure and behaviour, which would not be apparent if looking at either the technical or social sub-systems in isolation.[2]

If you ask any stakeholder of a socio-technical system if they want that system to be resilient, they will almost certainly say yes. What they might mean by this is often not clear, but loosely speaking, it often suggests that they want their system to survive and thrive under uncertain and changing circumstances. However, it is difficult to understand what the characteristics of a resilient system are, and how that system could be designed. This is partly because resilience is defined differently across and within domains; it is also linked to a set of other concepts including robustness, recovery and adaptability, which are themselves often poorly defined.

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[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:10.1016/j.sheji.2016.01.002.
[2] Kyle J. Behymer and John M. Flach, 'From Autonomous Systems to Sociotechnical Systems: Designing Effective Collaborations', *She Ji: The Journal of Design, Economics, and Innovation* 2, no. 2 (2016): 105–14, doi:10.1016/j.sheji.2016.09.001.

There is clearly a need to understand resilience if we are to design resilience into our systems. However, the systems that we want to be resilient are most often complex, with interconnected sub-systems that are both technical and social in nature. It may be possible to model and predict the behaviour of a single technical sub-system within a socio-technical system, however it is not possible to accurately predict the behaviour of the socio-technical system as a whole. In addition, socio-technical systems often have multiple stakeholders who each view the system from a different level of abstraction, with different perspectives on what the system's essential purpose and structure is. For these reasons, a systemic design approach is needed.

To achieve an understanding of resilience in design practice, we elicited perspectives on resilience from multiple stakeholders in a single socio-technical system: a development and infrastructure project at a leading European university. This involved a series of one-to-one interviews, each of which employed a system mapping exercise to structure our conversations about the system and its resilience. This paper reports on that study, exploring what can be learnt about resilience by eliciting, combining and contrasting the perspectives of multiple stakeholders of a socio-technical system. In doing so, we contribute an understanding of how to frame stakeholders' perspectives relative to a socio-technical system and how resilient socio-technical systems are able to change. We hope that this will help those designing socio-technical 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 conversations about resilience with stakeholders, we first looked across the literature to identify characteristics of resilience, and how to approach a study of a complex socio-technical system.

### Resilience across domains

In the general sense that we use it here, the word *resilience* originated with Holling's work in ecological and socio-ecological systems, where it was first defined as the persistence of system relationships and the ability of a system to absorb external changes.[3] The purpose of defining this new term was to account for the difference in engineered systems that are designed to reliably perform specific tasks with predictable external influences, and ecological systems that,

[3] C. S. Holling, 'Resilience and Stability of Ecological Systems', *Annual Review of Ecology and Systematics* 4 (1 January 1973): 1–23, doi:10.2307/2096802.

although they might lack stability, persist when confronting extreme change and uncertainty.[4] Over time, this concept was also applied in social and socio-ecological systems.[5] Whilst the application of the word resilience was extended 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, resilience concepts are now used widely across domains, including not just ecology and engineering, but also disaster risk management[6], community studies[7], economics[8] and psychology[9]. However, with this expanded range of application, the term resilience has grown from its original meaning to encompass a set of ideas about how systems can, or cannot, respond to external influences over their lifetime. Although descriptions of resilience vary, there are three main characteristics of resilience that we can 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. However, in this paper we view resilience as an overarching concept, with a resilient system exhibiting all three of these characteristics, whether at different times in the system's lifecycle or at different levels of abstraction.

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[4] C. S. Holling, 'Engineering Resilience versus Ecological Resilience', in *Engineering Within Ecological Constraints* (Washington, DC: National Academy of Engineering, 1996), 31–43.
[5] W. Neil Adger, 'Social and Ecological Resilience: Are They Related?', *Progress in Human Geography* 24, no. 3 (1 September 2000): 347–64, doi:10.1191/030913200701540465.
[6] Kristen MacAskill and Peter Guthrie, 'Multiple Interpretations of Resilience in Disaster Risk Management', *Procedia Economics and Finance*, 4th International Conference on Building Resilience, Incorporating the 3rd Annual Conference of the ANDROID Disaster Resilience Network, 8th – 11th September 2014, Salford Quays, United Kingdom, 18 (2014): 667–74, doi: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: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 (1 March 2010): 27–43, doi:10.1093/cjres/rsp029.
[9] Judith Johnson et al., 'Resilience to Emotional Distress in Response to Failure, Error or Mistakes: A Systematic Review', *Clinical Psychology Review* 52 (March 2017): 19–42, doi:10.1016/j.cpr.2016.11.007.

**TABLE 1: EXAMPLES OF HOW DEFINITIONS OF RESILIENCE IN DIFFERENT FIELDS RELATE TO THE THREE CHARACTERISTICS OF RESILIENCE**

| | R1 | | R2 | R3 | |
|---|---|---|---|---|---|
| | **Prevention** | **Impact minimisation** | **Recovery** | **Incremental change** | **Adaptability** |
| **Societal resilience**[10] | 'Resistance and maintenance' | | | 'Change at the margins' | 'Openness and adaptability' |
| **Seismic resilience**[11] | 'Reduced failure probabilities' | 'Reduced consequences from failures' | 'Reduced time to recovery' | | |
| **Supply chain resilience**[12] | 'Readiness and preparedness' | | 'Recovery or adjustment' | | 'Response and adaption' |
| **Engineering resilience**[13] | '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' | | |

As can be seen from Table 1, the emphasis placed on certain resilience characteristics varies according to the field of study. This can be attributed to the difference in the purpose or identity of the types of system considered. Bhamra et al. compiled a list of resilience definitions across domains, which highlights these differences.[14] For example, authors generally see the purpose of ecological systems as the preservation of living organisms, whereas, authors see the purpose of engineering systems as the fulfilment of specific, clearly defined tasks. Holling describes this difference as follows:

> *'One definition [of resilience] focuses on efficiency, constancy, and predictability – all attributes at the core of engineers' desires for fail-safe design. The other focuses on persistence, change, and unpredictability – all attributes embraced and celebrated by biologists with an evolutionary perspective.'*[15]

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[10] Stephen R. Dovers and John W. Handmer, 'Uncertainty, Sustainability and Change', *Global Environmental Change* 2, no. 4 (December 1992): 262–76, doi:10.1016/0959-3780(92)90044-8.
[11] Michel Bruneau et al., 'A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities', *Earthquake Spectra* 19, no. 4 (1 November 2003): 733–52, doi:10.1193/1.1623497.
[12] Serhiy Y. Ponomarov and Mary C. Holcomb, 'Understanding the Concept of Supply Chain Resilience', *The International Journal of Logistics Management* 20, no. 1 (22 May 2009): 124–43, doi:10.1108/09574090910954873.
[13] Ron Westrum, 'A Typology of Resilience Situations', in *Resilience Engineering: Concepts and Precepts* (Hampshire, UK: Ashgate Publishing, Ltd., 2006), 55–68.
[14] Ran Bhamra, Samir Dani, and Kevin Burnard, 'Resilience: The Concept, a Literature Review and Future Directions', *International Journal of Production Research* 49, no. 18 (15 September 2011): 5375–93, doi:10.1080/00207543.2011.563826.
[15] Holling, 'Engineering Resilience versus Ecological Resilience'.

In another domain, that of disaster and risk management, there is a focus on studying high impact, one-off events. There is an implication that for every hour that important parts of a system like a city are unable to function, people suffer and money is lost. Therefore in descriptions of resilience, the conceptual emphasis is placed on recovery and mitigation for 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]'*[16]

This domain effect is also evident in organisational resilience, (where the desire is to increase productivity and minimise variability), and psychology (where the desire is to increase personal capacity to bounce back from adversity).[17]

Unifying domain specific definitions of resilience is important because in practice the resilience of any one system will be affected, and to some extent determined, by other types of systems that it interacts with. These interactions happen across domains, with the resilience of one type of system having the potential to negatively impact the resilience of another type of system (e.g. a thriving social community having a negative impact on an environmental ecosystem).[18] These interactions also happen across different levels of abstraction, with the resilience of a system at one scale influencing the resilience of a system at another scale.[19]

## Resilience in socio-technical 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 in socio-technical systems. At a low level, it is desirable that technical systems are predictable, reliable and robust. For example, a car is designed to perform under a set of environmental conditions that have a predetermined range, such as temperature, road surface and impact forces. 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 system can be resilient, dealing with unexpected external events. In this

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[16] Bruneau et al., 'A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities'.
[17] Nick McDonald, ed., 'Organisational Resilience and Industrial Risk', in *Resilience Engineering: Concepts and Precepts* (Hampshire, UK: Ashgate Publishing, Ltd., 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 (1 March 2006): 25–44, doi:10.1177/1534484305285335.
[18] Adger, 'Social and Ecological Resilience'.
[19] David D. Woods, 'Essential Characteristics of Resilience', in *Resilience Engineering: Concepts and Precepts* (Hampshire, UK: Ashgate Publishing, Ltd., 2006), 21–34.

combined system, the car contributes the first characteristic of resilience – resilience as resisting influences – and the driver contributes the third characteristic – resilience as changing 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.[20] Some researchers have tried to address the challenge of designing changeable technical systems and found it necessary to take a socio-technical approach.[21]

Some researchers insist that engineers and designers of technical systems have a moral obligation to consider the wider social systems that they design for or within.[22] 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 entities that are often best understood on a socio-technical basis.[23]

The socio-technical systems that stakeholders must analyse, understand, and improve are often partially designed and partially evolved.[24] This requires stakeholders to grapple with the complexity of systems that they only incompletely understand and to interpret emergent behaviour that was not anticipated.[25] The function and structure of such systems will be perspective dependent. That is, two stakeholders might view the same system from a different level of abstraction, and only be aware of some of the social and technical sub-systems that are

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[20] Eloise Taysom and Nathan Crilly, 'Diagrammatic Representation of System Lifecycle Properties', in *Proceedings of the 4th International Engineering Systems Symposium (CESUN 2014)* (4th International Engineering Systems Symposium (CESUN 2014), Hoboken, NJ, 2014).
[21] Y. Melese, R. Stikkelman, and P. Herder, 'A Socio-Technical Perspective to Flexible Design of Energy Infrastructure Systems', in *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, 2016, 004669–74, doi:10.1109/SMC.2016.7844968.
[22] Pieter Vermaas et al., *A Philosophy of Technology: From Technical Artefacts to Sociotechnical Systems*, Synthesis Lectures on Engineers, Technology and Society (San Francisco, CA: Morg an & Claypool Publishers, 2011).
[23] Peter Kroes et al., 'Treating Socio-Technical Systems as Engineering Systems: Some Conceptual Problems', *Systems Research and Behavioral Science* 23, no. 6 (1 November 2006): 803–14, doi:10.1002/sres.703.
[24] Olivier de Weck, Daniel Roos, and Christopher Magee, *Engineering Systems: Meeting Human Needs in a Complex Technological World* (MIT Press, 2011).
[25] Regina Frei and Giovanna Di Marzo Serugendo, 'Concepts in Complexity Engineering', *International Journal of Bio-Inspired Computation* 3, no. 2 (2011): 123–139; Regina Frei and Giovanna Di Marzo Serugendo, 'Advances in Complexity Engineering', *International Journal of Bio-Inspired Computation* 3, no. 4 (2011): 199–212; 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 (1 July 2016): 291–305, doi: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', Primer, accessed 24 February 2017, http://complexityprimer.eng.cam.ac.uk/.

relevant at that level. In socio-technical systems theory, multiple levels of abstraction are grouped into three categories: 'primary work systems' (e.g. sub-systems of a whole organisation), 'whole organization systems' and 'macrosocial systems' (e.g. national institutions).[26] In this study, we use a similar approach to understand resilience in the context of a socio-technical system, combining individual stakeholder perspectives over different types of system and at different levels of abstraction.

## Research methodology

The study was designed as a series of in-depth interviews with stakeholders of a single system. The system chosen was a €1 billion development in a city, initiated and managed by a leading European university. The initiative was designed to provide affordable housing for university staff and post-graduates and provide a place to foster university research. The development had long term goals to enhance the university and city, with the term 'resilience' being used in project reports relating to both technical (buildings) and social (communities) systems. For example, in the development documentation and news articles, consideration of resilience is evident in claims about '*designing in adaptive measures to ensure resilience to the impacts of climate change' and 'planning resilient neighbourhoods' that will be future proof for hundreds of years.* The interviews were conducted between March and August, 2016. At this point, 75% of the 'phase one' development had been built, although no residents had moved in. Further phases of development were planned to extend the site, with the building stage of the project expected to take 15 years in total. To protect the anonymity of the participants in this study, further details of the development, including its location and the organisations involved, have been withheld.

### Sample

In the study 11 stakeholders were interviewed. They were chosen to span across domains and levels of abstraction as shown in Table 2. The stakeholders were identified through a combination of direct contact and chain referral sampling.[27]

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[26] E.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 (Ontario Ministry of Labour, Ontario Quality of Working Life Centre, 1981).
[27] Patrick Biernacki and Dan Waldorf, 'Snowball Sampling: Problems and Techniques of Chain Referral Sampling', *Sociological Methods & Research* 10, no. 2 (1 November 1981): 141–63, doi:10.1177/004912418101000205.

**TABLE 2: SYSTEM STAKEHOLDERS, THEIR JOB ROLES, ORGANISATIONAL AFFILIATION, AND THE SYSTEM THEY IDENTIFIED AS THEIR MAIN SYSTEM OF INTEREST.**

| Stakeholder ID | Job role* | Organisation | System of interest* |
|---|---|---|---|
| S1 | Community development officer | Local authority | City |
| S2 | Councillor | Local authority | City |
| S3 | Planning officer | Local authority | City |
| S4 | Academic | University | University |
| S5 | Academic and governor | University | University |
| S6 | Former project director | University (project team) | Development |
| S7 | Acting project director | University (project team) | Development |
| S8 | Construction director | University (project team) | Development |
| S9 | Operations director | University (project team) | Development |
| S10 | Architectural firm director | Consultant architects | Lot A** |
| S11 | Architectural firm director | Consultant architects | Lot B |

*As defined by the stakeholder in the interview when selecting a system boundary.

**The development project was sub-divided into physical lots, with different architectural firms contracted to design each lot.

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

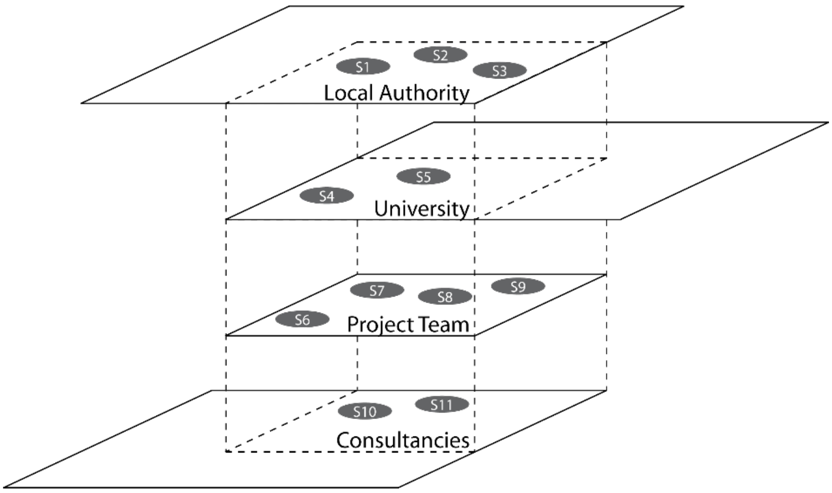


**FIGURE 1: SCHEMATIC SHOWING THE DISTRIBUTION OF THE STAKEHOLDERS ACCORDING TO THE ORGANISATION THEY WORKED FOR. THE PROJECT TEAM IS EMPLOYED BY THE UNIVERSITY SOLELY TO IMPLEMENT THE DEVELOPMENT BUT IS TREATED AS AN INDEPENDENT ORGANISATION. THE STAKEHOLDERS INTERVIEWED WERE ALL INVOLVED WITH THE DEVELOPMENT PROJECT AND SO ARE**

**SHOWN WITHIN THE DOTTED LINES. THE LOCAL AUTHORITY, UNIVERSITY AND CONSULTANCIES ALL HAVE PARTS OF THE ORGANISATION THAT ARE NOT INVOLVED WITH THE DEVELOPMENT PROJECT, ILLUSTRATED BY THE EXTENSION OF THE PLANES BEYOND THE DOTTED LINES.**

## Data collection

All interviews were conducted one-to-one at the stakeholders' place of work with the first author as the interviewer. Each session lasted 53 minutes on average (excluding the introduction and wrap up). With the participants' consent, all interviews were recorded and subsequently converted into a total of over 60,000 words of transcript. A structured interview format was used 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.[28]

The interviews had two main parts. In the first part, the stakeholders were asked 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 to gauge each stakeholder's initial level of understanding of resilience. After the initial discussion, the interview moved onto the second part, which involved a system mapping exercise.

### System mapping exercise

In the system mapping exercise the stakeholders were asked to choose a system boundary that reflected their level of abstraction. For example, a stakeholder involved in running the university might think about the university as their main system, with a new development as one sub-system 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 sub-system of the city. Each system mapping exercise was conducted from the perspective of the individual stakeholder.

The mapping exercise started with a blank sheet of A3 paper. The interviewer started by explaining the exercise and drawing a large rectangle as a system boundary. Starting the exercise this way, as opposed to having pre-printed sheets, was intended to make the exercise

[28] Michael Quinn Patton, *Qualitative Evaluation and Research Methods (2nd Ed.)* (Thousand Oaks, CA, US: Sage Publications, Inc, 1990).

more approachable and reduce anxiety around visual literacy.[29] Once this boundary was drawn, the stakeholders were asked to:

1. Label the system boundary
2. Write a system purpose for the specified boundary 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 coloured dots to each sticky note to represent the three resilience characteristics (resist – red, recover – blue, change – green)
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 can be 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 sub-systems that are not people'.

[29] Anna Bagnoli, 'Beyond the Standard Interview: The Use of Graphic Elicitation and Arts-Based Methods', *Qualitative Research* 9, no. 5 (1 November 2009): 547–70, doi: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 (1 August 2006): 341–66, doi:10.1177/1468794106065007.

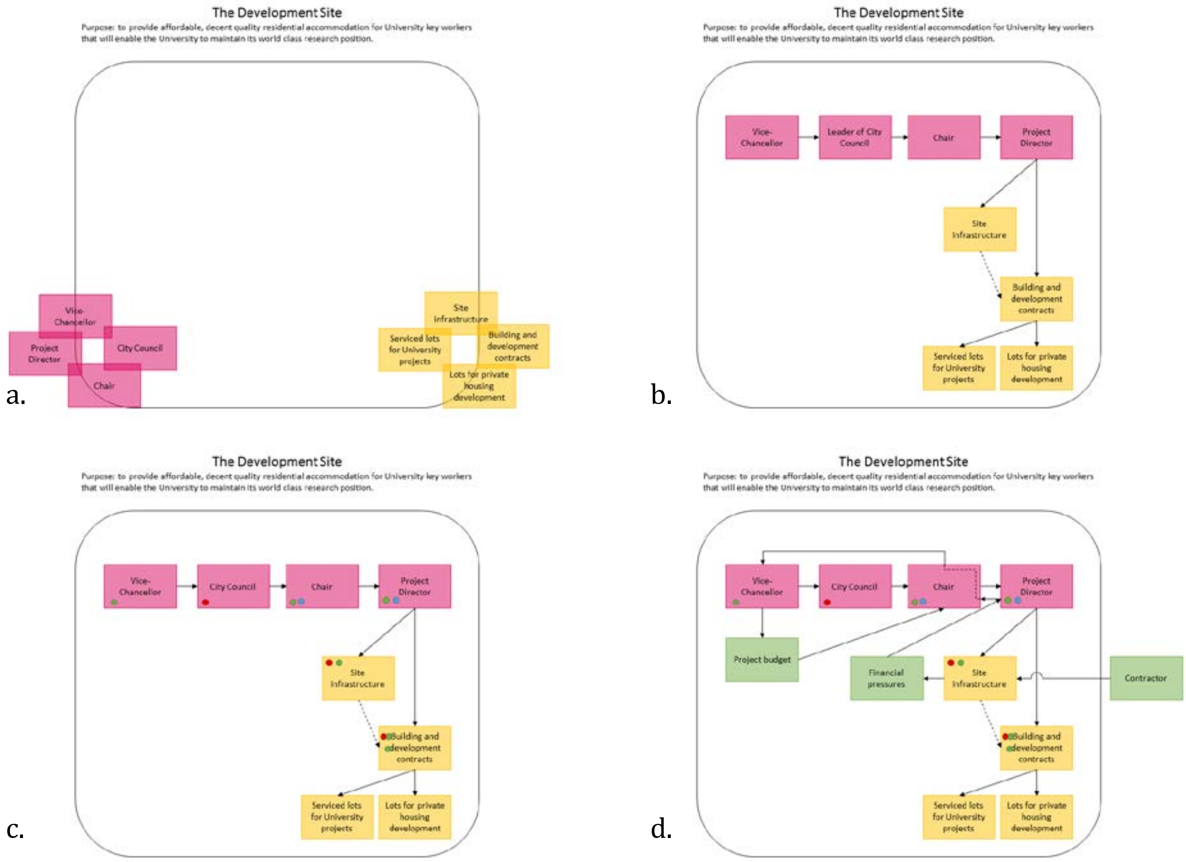


**FIGURE 2: FOUR SEQUENTIAL STAGES OF THE SYSTEM MAPPING EXERCISE:**
**A. STEPS 1-4: DEFINING A SYSTEM BOUNDARY ['THE DEVELOPMENT SITE' IN THIS INSTANCE], SYSTEM PURPOSE, IDENTIFYING 'PEOPLE' [PINK] AND 'THINGS' [YELLOW] AS SUB-SYSTEMS;**
**B. STEP 5: ARRANGING SUB-SYSTEMS AND DRAWING RELATIONSHIPS;**
**C. STEP 6: IDENTIFYING RESILIENCE CHARACTERISTICS FOR EACH SUB-SYSTEM;**
**D. STEP 7: EXPLORING AND DEVELOPING THE SYSTEM MAP BASED ON FURTHER DISCUSSION [ADDITIONS IN GREEN].**

The stakeholders were free to draw relationships as they chose, using lines or directional arrows. Some of the variety of system maps can be seen in Figure 3. There were also no constraints on what type of 'thing' the sub-systems had to be. For instance, the stakeholders chose to include physical things like buildings, contractual things like budgets or legal contracts, and abstract things like reputation or performance. Similarly, the 'people' could be individuals, groups or organisations, as defined by the stakeholders.


**FIGURE 3: A SAMPLE OF FOUR STAKEHOLDERS' COMPLETED SYSTEM DIAGRAMS.**

## Data analysis

The interview transcripts (covering both the initial discussion and system mapping exercise) were qualitatively coded in Atlas.ti using a pre-defined code list, which was developed from a previous research study. Although a code list was used, it was expected that new codes would emerge from the data during an iterative inductive process.[30] A second researcher was asked 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.

The findings from this study are discussed in three parts: the factors that frame an individual stakeholder's perspective; how these perspectives can be used to understand resilience; and findings from taking a socio-technical approach. Each of these parts will be discussed in turn supported by quotes from the data. In some cases these quotes have been edited for clarity or to protect the anonymity of stakeholders.

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[30] David R. Thomas, 'A General Inductive Approach for Analyzing Qualitative Evaluation Data', *American Journal of Evaluation* 27, no. 2 (1 June 2006): 237–46, doi:10.1177/1098214005283748.

# 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 by the system mapping exercise but it varied between participants and had a large impact on how they discussed resilience.

## System boundary and purpose

In the system mapping exercise, the stakeholders first defined a system boundary, which was 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 an individual lot on the development. The purposes that the stakeholders assigned to these systems can be seen in Table 3.

**TABLE 3: SYSTEM 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 character with a green belt and transport links. |
| S3 | City | To provide affordable housing. |
| S4 | University | To retain a world-class academic environment which continues 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 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 | Lot | To provide design coordination. |
| S11 | Lot | To provide a network of spaces to support communal life. |

The list of purposes in Table 3 show 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, i.e. maintaining competitiveness. Conversely, those in more specialised roles considered the development at a different level of abstraction. For example, the construction director (S8) also defined the development site as their system boundary but identified the purpose of the system as the production of buildings and infrastructure. In practice, these boundaries and purposes were framed by the job role of the stakeholders and the people and things they interact with on a day-to-day basis:

*'I'm responsible for the design, procurement and construction. […] I interact very closely with the rest of the project team and I have to make sure that 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*

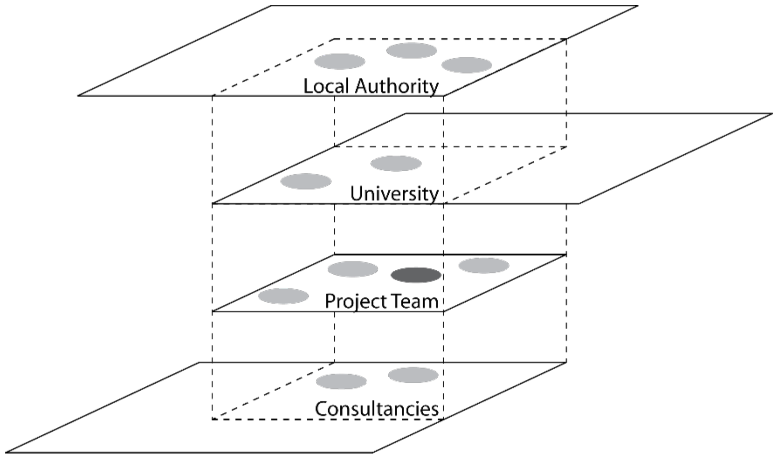


**FIGURE 4: STAKEHOLDER S8'S POSITION IN THE SYSTEM (DARKER DOT) RELATIVE TO THE OTHER STAKEHOLDERS.**

These differences in stakeholder purposes may seem trivial, however these boundaries and purposes determine what the stakeholders identified as most important in the system. For example, when constructing the system map, stakeholder S6 chose social systems involved in governance (e.g. university governance, local authority, and project team), whereas stakeholder S8 chose social systems from a 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 sub-systems a stakeholder considers from their perspective. It is only by making these factors explicit that we can understand how stakeholders view resilience. This can be seen in the discussion with stakeholder S5, who defined their system's purpose as maintaining the university's research outputs. When asked to relate this purpose to resilience they said:

*'Whatever kind of institution we are in 50 years, the 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*

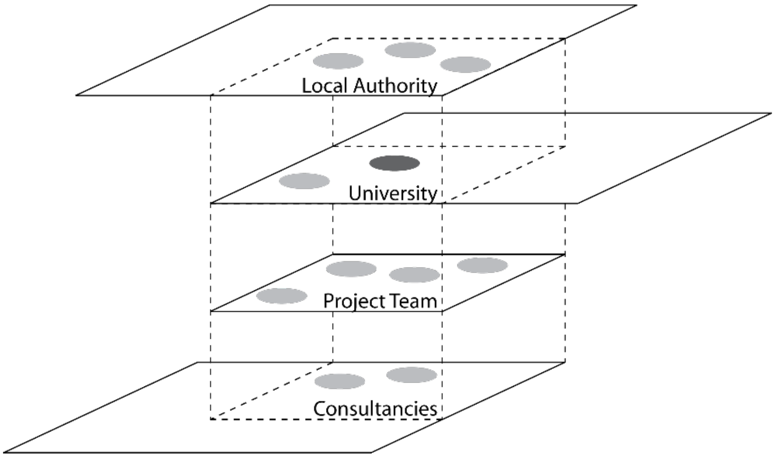


**FIGURE 5: STAKEHOLDER S5'S POSITION IN THE SYSTEM (DARKER DOT) RELATIVE TO THE OTHER STAKEHOLDERS.**

This contrasts with the project teams' goal of providing affordable accommodation, and there are implications for the design of the buildings on the development. For the project director cost is a major driver whereas for the stakeholders operating at the university level (S4 and S5), the legacy of the buildings was deemed more important than its 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 something that 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 are ultimately responsible for delivering a technical system (the development buildings and infrastructure) following a plan and 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 defined. The architect quoted above described this process:

> *'It's going from the micro to the macro. So at one level you're working at town planning level 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 moving 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. This means that even a single stakeholder can 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 which was largely defined by their job role but also was affected by other parameters that were harder to define including personal values and domain outlook. For example, one stakeholder's job required them to be involved for a short period of time in the planning of a development, but as part of that planning role, they had to think ahead to how the finished development would operate. In addition, they also lived in the city so were concerned about the impact of the development on that city in the long term. This stakeholders' 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 system timescale were layered and multi-faceted. The relationship between time and perspective was also interdependent; the timescale the stakeholders thought about affected their perspective, and the stakeholders' 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 a lot on the development. One of these architects, S10, defined their 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 (e.g. contractors, acoustic noise criteria and design codes). However, the other architect, S11, framed the discussion around the development as a place, which was the product of their design process. This stakeholder defined the system purpose as 'To provide a network of spaces to support communal life.' Correspondingly the systems identified in the system map were related to the development as a living environment (e.g. residents, buildings and public spaces). Defining the system 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',[31] which are detailed in Table 4.

[31] Adam Ross and Donna Rhodes, 'Using Natural Value-Centric Time Scales for Conceptualizing System Timelines through Epoch-Era Analysis' (INCOSE 2008 International Symposium, Utrecht, The Netherlands, 2008).

**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.

The stakeholders have been mapped to these three epochs in Figure 6 according to what was discussed in each interview. 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 showing other epochs that were covered by each stakeholder. The dotted vertical line shows the point in time when the interviews were conducted (early 2016). 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.

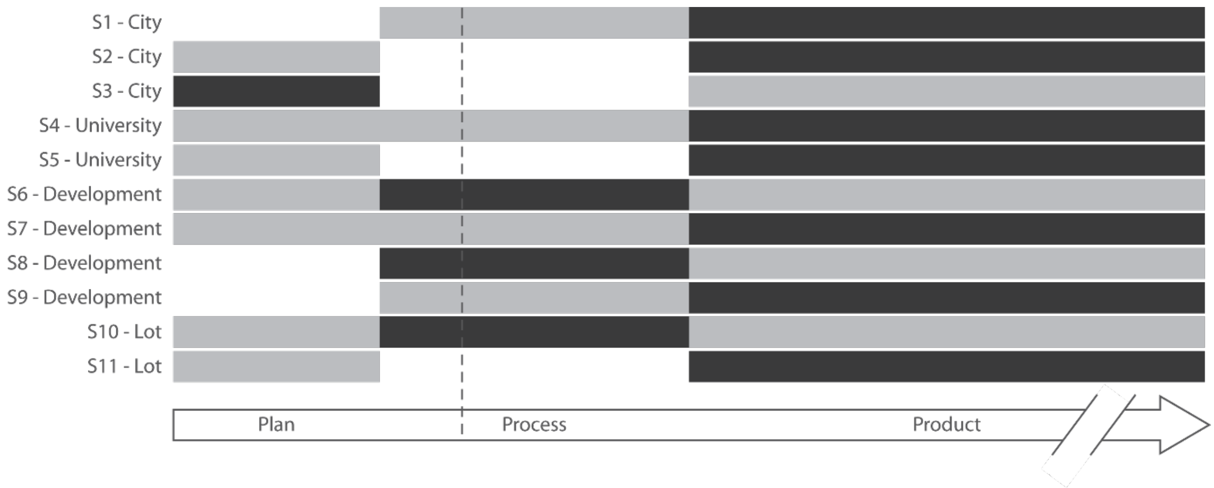


**FIGURE 6: SYSTEM TIMELINE DIVIDED INTO THREE EPOCHS: PLAN, PROCESS, AND PRODUCT. STAKEHOLDERS ARE MAPPED ONTO THE TIMELINE WITH HORIZONTAL BARS REPRESENTING THE EPOCHS THAT WERE DISCUSSED IN EACH INTERVIEW. THE DARKEST LINES SHOW THE EPOCHS THAT EACH STAKEHOLDER FOCUSED ON IN THE SYSTEM MAPPING EXERCISE.**

All of the stakeholders were interviewed in the fourth year of the 'process' stage of the development. This means that the 'plan' timescale is based on what has already happened, whilst the 'process' timescale is based on current project plans, and the 'product' timescale is based on design practice (e.g. the architects said that they generally design buildings to last for 60 years). There were a few discrepancies for the 'product' length of time, with some stakeholders saying they thought about what the development would be like in 100-250 years' time. However, an outlook of 60 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 who were managing their respective systems. These stakeholder's 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 (e.g. S2 and S3).

## 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 describing how they thought the resilience for the development came from the university, realised 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 organisations that are working on the ground, like the school and the community centre.' – S7*

Although, as one stakeholder pointed out, having a social system present across multiple epochs, as 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 involved only for part of a system's timespan 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 define an interface between them, such as a contract. Looking across epochs in the study highlighted interfaces as an important aspect of resilience across many different types of system. These 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 planning stage of a building and the implementation |
| Structural | The organisational structure of the project team | A physical interface between a lot and the rest of the development |

The data from the interviews also gave us an insight into how these types of systems can change. The stakeholders gave examples of system change when labelling sub-systems with resilience characteristics. In most cases, it was possible to identify an influence, which initiated the change, and agent, which enabled the change in response to the influence. Although, the change agents were at times hard to identify. For example, in some cases the influence and change agent appeared to be the same entity, however, on closer inspection there appeared to be a chain of influences and agents. Stakeholder S10 described how they, as 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 it.'*

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

> *'We had to accommodate additional apartments because they couldn't fit them on another lot so our buildings got bigger. But the design proved we could accommodate those changes as we went along.'*

From this description, the situation looks more complicated. It seems that the design requirements for this lot were influenced by other lots. So the project team then made a change to the architect's design requirements (i.e. how many apartments they have to fit onto their lot). The project team influenced the architect to accept these design changes but the changes were only possible because the lot design was flexible enough to be changed by the architects.

It should be noted that the choice that stakeholders make about whether a system resists, recovers or changes, is also dependent on their perspective on the system. For example, in the above example, the architect said that the lot design was able to change. Some people could view that change as a recovery – the architect was told the existing design would no longer work, and the architect then had to recover. 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 – that is they faced a negative external influence – then this was classed as recovery. Whereas, when social systems proactively changed – taking advantage of a new opportunity – then this was classed as changing to accommodate influences.

For all types of system it appeared that when stakeholders were discussing systems that lasted over long periods of time, they were 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 the long established organisation but that organisations 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 project team running the development project, which they see as separate from the university. However, this project team is in fact employed by and under the direction of the university. 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 said, the university has shown a lot of foresight in doing 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 in 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 characterised as unable to change in response to influences by a stakeholder if they are 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 in a socio-technical system

Taking a socio-technical 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 labelled as R1 (resist) was equal across social and technical systems. Whereas, for R2 (recover) and R3 (change), 60% of systems allocated with these characteristics were social and 40% were technical. These distributions were reflected in how 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 that was described by stakeholders. In general, social systems were able to change in response to influences without requiring outside intervention; an internal agent facilitates the change. In contrast, when technical systems changed they required an external social system to act as a change agent. This difference in the way that social and technical systems change framed stakeholders' perspectives on how resilience can be achieved. For example, one stakeholder reasoned that resilience comes from changing stakeholder attitudes, which will mean that better decisions will be 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 9 of the 11 stakeholders interviewed. They said that social systems, rather than technical systems, contributed most to the resilience of a socio-technical system. The technical systems were perceived as the 'end product' created by social systems or the 'structure' that supports social systems. Some stakeholders went as far to say that social systems can 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 systems were implicated as being negative influences, and the socio-technical system as a whole was deemed to have failed. This suggests that, because stakeholders view the purpose of technical systems 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

Taking a socio-technical approach is an effective way to analyse resilience, and related concepts, in systems that are more conventionally approached from either a social or technical perspective (e.g. communities and infrastructure respectively).[32] In this study we have confirmed this finding by demonstrating that a holistic analysis of a socio-technical 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 systemic design approach to resilience. These include: system domain, stakeholder purpose, system abstraction, and timescales. These factors must be considered from multiple stakeholder viewpoints because how you define a system's resilience is dependent on perspective.

In the resilience literature, the perspectives of individual stakeholders in a socio-technical system are not explored. Despite this, resilience is often defined with respect to a negative outcome or influence, such as, 'The ability to prevent something bad from happening'.[33] Whether an outcome or influence is 'bad' is dependent on perspective. Therefore, for a complex socio-technical system with many stakeholders, there will be different perspectives on what resilience means for a specific system. This study also illustrated that each stakeholder can have a localised view of a system. Therefore different stakeholders can view the same system as having different structures, functions and timescales. 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.[34]

Although there is some literature that takes a socio-technical approach to researching resilience, these studies tend to be domain specific. To avoid domain specificity, this present

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[32] Melese, Stikkelman, and Herder, 'A Socio-Technical Perspective to Flexible Design of Energy Infrastructure Systems'; Baek, Meroni, and Manzini, 'A Socio-Technical Approach to Design for Community Resilience'.
[33] Westrum, 'A Typology of Resilience Situations'. 59
[34] Baek, Meroni, and Manzini, 'A Socio-Technical Approach to Design for Community Resilience'.

study used three characteristics, which were shown in Table 1 to have applicability across domains. These characteristics were then applied to social and technical systems irrespective of domain. In doing this we have demonstrated how social and technical systems display different resilience characteristics and the types of socio-technical interactions that lead to resilience. This has implications for systemic design, offering a generalisable approach to understanding resilience in socio-technical systems.

At the beginning of resilience research, a clear distinction was made between ecological resilience and engineering resilience, whereas social resilience was generally seen as equitable to ecological resilience.[35] 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 socio-technical systems by being adaptable, and at times, technical systems limited the ability of the socio-technical systems to change even when change was desirable. However, stakeholders appeared to be using these properties to structure and control socio-technical system complexity. 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 are not made explicit or related to the system parameters that we have identified here.

## Conclusions

Whilst many studies consider the resilience of individual systems from a specific perspective, most large socio-technical systems are really a constellation of systems with many stakeholders each with their own (or many) perspectives. This study has furthered 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 across stakeholder perspectives on a single socio-technical system, we have shown it is possible to get new insights 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.

[35] Holling, 'Engineering Resilience versus Ecological Resilience'; Adger, 'Social and Ecological Resilience'.

This study was conducted on a development project, but by categorising the sub-systems broadly into either 'social' or 'technical' and using three overarching resilience characteristics, we expect the findings to be generalisable. This is confirmed by the consistency of our findings with other domain-specific studies. For example, the epoch divisions of plan, process, product are common across many designed, or partially designed, systems. To build on our findings, the multi-stakeholder approach adopted here could be used to explore resilience in other types of socio-technical system. We have shown that by taking a systemic approach, we can overcome the problems of communicating with stakeholders across domains, realising new insights into both how to frame stakeholder perspectives on resilience and what these perspectives can reveal about what makes socio-technical systems resilient.