OCAD University Open Research Repository

2018

The visual representation of complexity: Sixteen key characteristics of complex systems

Boehnert, Joanna

Suggested citation:

Boehnert, Joanna (2018) The visual representation of complexity: Sixteen key characteristics of complex systems. In: Proceedings of RSD7, Relating Systems Thinking and Design 7, 23-26 Oct 2018, Turin, Italy. Available at http://openresearch.ocadu.ca/id/eprint/2737/

Open Research is a publicly accessible, curated repository for the preservation and dissemination of scholarly and creative output of the OCAD University community. Material in Open Research is open access and made available via the consent of the author and/or rights holder on a non-exclusive basis.

The OCAD University Library is committed to accessibility as outlined in the Ontario Human Rights Code and the Accessibility for Ontarians with Disabilities Act (AODA) and is working to improve accessibility of the Open Research Repository collection. If you require an accessible version of a repository item contact us at repository@ocadu.ca.

The Visual Representation of Complexity: Sixteen Key Characteristics of Complex Systems

Boehnert, Joanna [a]*

[a] Loughborough University

* j.j.boehnert@lboro.ac.uk

Abstract

Sustainability practitioners have long relied on images to visualise complex ideas and display relationships in complex adaptive systems on various scales and across domains. This research addresses the need for visual representations of complexity that are widely understood in different fields and sectors. The project used a participatory concept mapping process to identify, define and illustrate 16 key characteristics of complex systems and contribute to an evolving visual language of complexity. This research was initially funded by CECAN (Centre for the Evaluation of Complexity Across the Nexus) at the University of Surrey with the aim to facilitate communication, learning, collaboration and evaluation within the CECAN network. The research sought to aid researchers, policy makers, design practitioners and evaluators develop a shared understanding of systemic processes. This paper describes the research process and reflects on its contribution.

Keywords: complexity, visualisation, systems, concept mapping

1. Introduction

Images have traditionally played a role in facilitating communication and collaboration on social, economic, technological, environmental and biological issues that are characterized as complex systems. Complexity science is associated with an emerging systems "field of fields" across disciplines including design, public health, education, management, earth sciences, engineering, biology and ecology, sustainability, and science in general (Cabrera & Trochim 2006, 2). Within these systems approaches to knowledge, complex adaptive systems are described as "systems in which the individual behavior of agents following simple local rules leads to complex and emergent properties" (Cabrera 2008, 1). This relationship between simple rules and complexity is described by Nobel laureate Murray Gell-Mann:

> What is most exciting about our work is that it illuminates the chain of connections between, on the one hand, the simple underlying laws that govern the behavior of all matter in the universe and, on the other hand, the complex fabric that we see around us, exhibiting diversity, individuality, and evolution. The interplay between simplicity and complexity is the heart of our subject (1995/1996, 3).

The 'simple rules' that govern complex systems are foundational for systems work. These rules are continuously defined by communities that study complex systems as systems knowledge evolves. The research described in this paper aims to consolidate knowledge on a few of the most useful 'simple rules' or key characteristics of complex systems with the creation of new visual icons. Using a participatory visualisation and conceptual mapping method, the research aims to contribute to an evolving visual language of complexity.

With this research I sought to design new visual representations of key features of complexity. The project was initially funded by CECAN (Centre for the Evaluation of Complexity Across the Nexus)[1] for a period 16 days over six months. Loughborough University supported the final documentation and dissemination of this work including this paper. The project employed participatory knowledge visualisation and concept mapping research methods. The process involved identifying key concepts, collecting ideas and images from the systemic design research community (at the Relating Systems Thinking And Design symposium - RSD6 Oslo) and then making space for deliberation and the generation of new visual outcomes. Best visual practices were identified and used to make the final visualisations. The final outcomes were published as a poster that identifies, defines and illustrates 16 key characteristics of complex systems. This paper describes the research process, reflects on its progress and speculates on its contribution.

[1] The Centre for the Evaluation of Complexity Across the Nexus (CECAN) is a research centre hosted by the University of Surrey working on policy evaluation in Nexus areas (food, energy, water and the environment).

2. Methods

The research used participatory mixed methodologies drawing on ideas from systems-oriented design (Sevaldson 2013; Jones 2014, 2014), knowledge visualisation (Masud *et al*. 2010) and concept mapping (Greene & Caracelli, 1997; Trochim and Cabrera 2005) practices. These approaches enabled knowledge sharing between a community of designers working on systems (at RSD6 and RSD7) and the evaluation community at CECAN. Concept mapping has particular methodological relevance to the research objectives. In the tradition described by William Trochim and Derek Cabrera, concept mapping allows shared conceptual frameworks to emerge while enabling groups to address the adaptive properties associated with complexity:

> The method is consistent with an evolving paradigm of complex adaptive systems thinking and helps groups address complexity in several ways: it is inductive, allowing shared meaning to emerge; it is based on a simple set of rules (operations) that generate complex patterns and results; it engages diverse agents throughout the process through a range of participation channels (synchronous or asynchronous web, face-to-face, etc.); the visual products -- the concept maps, pattern matches, action plots -- provide simple high-level representations of evolving thinking; the results are generative, encouraging shared meaning and organizational learning while preserving individuality and diversity; the maps themselves provide a framework that enables autonomous agents to align action with broader organizational or systems vision (Trochim and Cabrera 2005, 3-4).

The concept mapping method provides a robust theoretical foundation for the research project. According to Trochim and Cabrera, there are six major steps in concept mapping processes:

1. Preparation and Focus Formulation
2. Generation of Ideas or Issues
3. Structuring of Ideas or Issues
4. Representation of Ideas or Issues
5. Interpretation of Results
6. Utilization of Results (Trochim and Cabrera 2005, 4-7; Trochim, 1989)

In this project, these steps were developed over the six months period. Step 1, Preparation and Focus Formulation, was conducted with the research proposal and initial conversations with the CECAN working group. Step 2, Generation of Ideas, was enacted at RSD6 with the surveys. These surveys resulted in a rich source of primary data as a starting point for the two workshops in Step 3, Structuring Ideas. Step 4, Representation of the Ideas occurred during the months after the workshops when I created new visual representations of the key concepts. These visual outcomes were then refined during Step 5 as I received feedback from the CECAN working group and from the RSD7 community where I presented the final outcomes (a poster and paper). Currently, the work is in the Step 6 Utilization of Results stage as evidenced on multiple reference to the project on Twitter by practitioners and academics. The research used a range of participatory processes including: surveys, design crits, sketching workshops, Twitter interactions, emails and phone conversations. The results are new visualisations as high-level representations of the thinking of at least two communities of systems practitioners (RSD6 and CECAN).

3. Research Process

3.1 Preparation and Project Formulation: Proposal and Initial Conversations

The project started with a research proposal submitted to CECAN in an open call for proposals in July 2017. I proposed a participatory practice-based research project that was originally titled: 'A Typology of Visual Codes for Systemic Relations'. The project aimed to bring design knowledge and skills to CECAN and its stakeholders by addressing

> the need for images that are widely understood across different fields and sectors in order to facilitate conversations and decisions making between researchers, policy makers, practitioners and evaluators (with varying degrees of familiarity with complexity science). By attempting to identify the best visual practices and standardise visual codes used to represent the features of complex systems (such as tipping points or thresholds; domains of relative stability; levers and hubs; time-dependent evolution; feedback loops; emergence and self-organisation; adaptation, etc.) this project will contribute to the evolving the visual language used to communicate complexity (Boehnert 2017).

I proposed to do this work using systems-oriented design and knowledge visualisation approaches. The proposed research process included a survey of relevant imagery, two workshops and close collaboration with the CECAN research group (Alex Penn, Pete Barbrook-Johnson, Martha Bicket and Dione Hills) during the 16-day fellowship over several months. With this short design research project, I aimed to refine approaches to the visual communication of complex systems within and beyond the community of evaluators at CECAN.

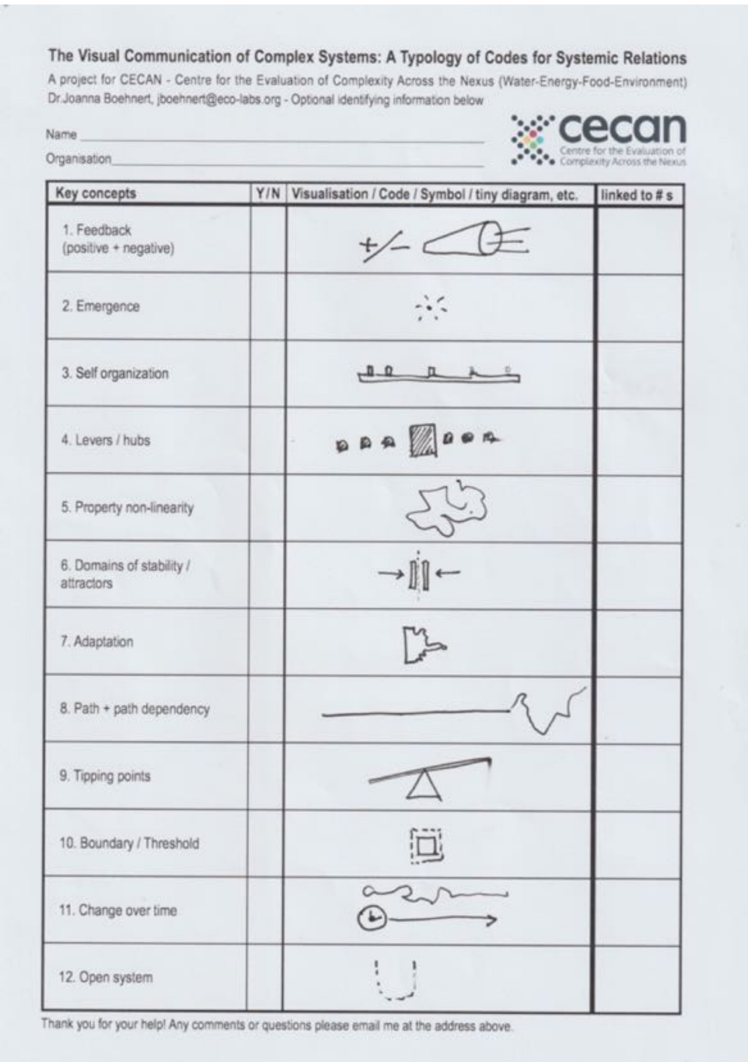
Once the proposal was accepted, the project started with conversations with a CECAN research group. These conversations clarified organisational priorities and goals for the research project. As I worked with the CECAN research group exploring potential outcomes, I modified my initial research proposal to accommodate their newly articulated concerns and newly identified project goals. A new research process was designed to identify, define and illustrate key characteristics of complexity with surveys and participatory design research to inform the design of new visual outcomes as illustrative icons rather than codes (which would have been symbolic devices that did not resemble the concepts). The name of the research project was changed to reflect the new priorities.[2]

The first step was to identify the specific features to be illustrated. Initially 12 characteristics of complexity were identified by the CECAN research group (four more were added later). Once this initial stage was completed, I sought to gather information from communities both inside and outside the CECAN network. The surveys at RSD6 were not written into the original proposal. This step emerged as I was presenting another research paper at the RSD6 conference and I noted the convergence of systemic designers provided an unique opportunity to harvest ideas on visual representations of complexity. The RSD6 organisers agreed to a last-minute request to engage delegates at the conference and made space in the plenary for a short presentation and survey.

[2] This change from codes to icons made the project significantly more time consuming.

3.2 Generation of Ideas: Surveys at RSD6 Oslo

In order to gather ideas from academics, sustainability practitioners and designers with expertise in the visualisation of complexity and systemic design, I conducted a survey at the Relating Systems Thinking and Design RSD6 The Environment, Economy, Democracy: Flourishing Together RSD6 conference (at the Oslo School of Architecture and Design, Oslo, Norway, October 18-20, 2017). I was offered a last-minute opportunity to run a participatory session at the RSD6 plenary. After a brief introduction, I distributed 50 surveys with 12 key characteristics of complexity in a room with approximately a hundred people. I asked the group to work in pairs to visualise each concept. Audience participation, including pictures of multiple surveys, is documented on the #RSD6 hashtag on Twitter. The survey (figure 1) include spaces for participants to sketch visual responses. I collected 46 surveys and two additional survey sheets submitted on Twitter. Each survey contain visual responses for some or all characteristics. This work produced a rich starting point for the creation of new visual outcomes.


The Visual Communication of Complex Systems: A Typology of Codes for Systemic Relations
A project for CECAN - Centre for the Evaluation of Complexity Across the Nexus (Water-Energy-Food-Environment)
Dr.Joanna Boehnert, jboehnert@eco-labs.org - Optional identifying information below

Name

Organisation

cecan
Centre for the Evaluation of Complexity Across the Nexus

Key concepts	Y/N	Visualisation / Code / Symbol / tiny diagram, etc.	linked to # s
1. Feedback (positive + negative)		+/−	
2. Emergence			
3. Self organization			
4. Levers / hubs			
5. Property non-linearity			
6. Domains of stability / attractors			
7. Adaptation			
8. Path + path dependency			
9. Tipping points			
10. Boundary / Threshold			
11. Change over time			
12. Open system			

Thank you for your help! Any comments or questions please email me at the address above.

Figure 1. Sample completed survey at RSD6

3.3 Structuring of Ideas: CECAN Participatory Workshops London

After the RSD6 conference, I organised the images from the surveys. The 46 surveys included 12 images on each survey (but not all surveys were complete). The results were several hundred individual images. I collected all icons for each characteristic on its own sheet using a scanner and Photoshop to digitally manipulate the images. The individual images for each characteristic were organised by type on two axes to reflect visual devices and strategies employed (see figures 2 to 13). The icons were organised according to types of abstractions. This visual sorting strategy enabled the identification of patterns as it became clear that most characteristics were commonly understood with similar visual conventions – although there were also random, unique and provocative interpretations. I published a blog on the research process on the CECAN website that included the survey characteristic sheets. These sheets become the starting point for the next stage of the project: the CECAN participatory workshops.

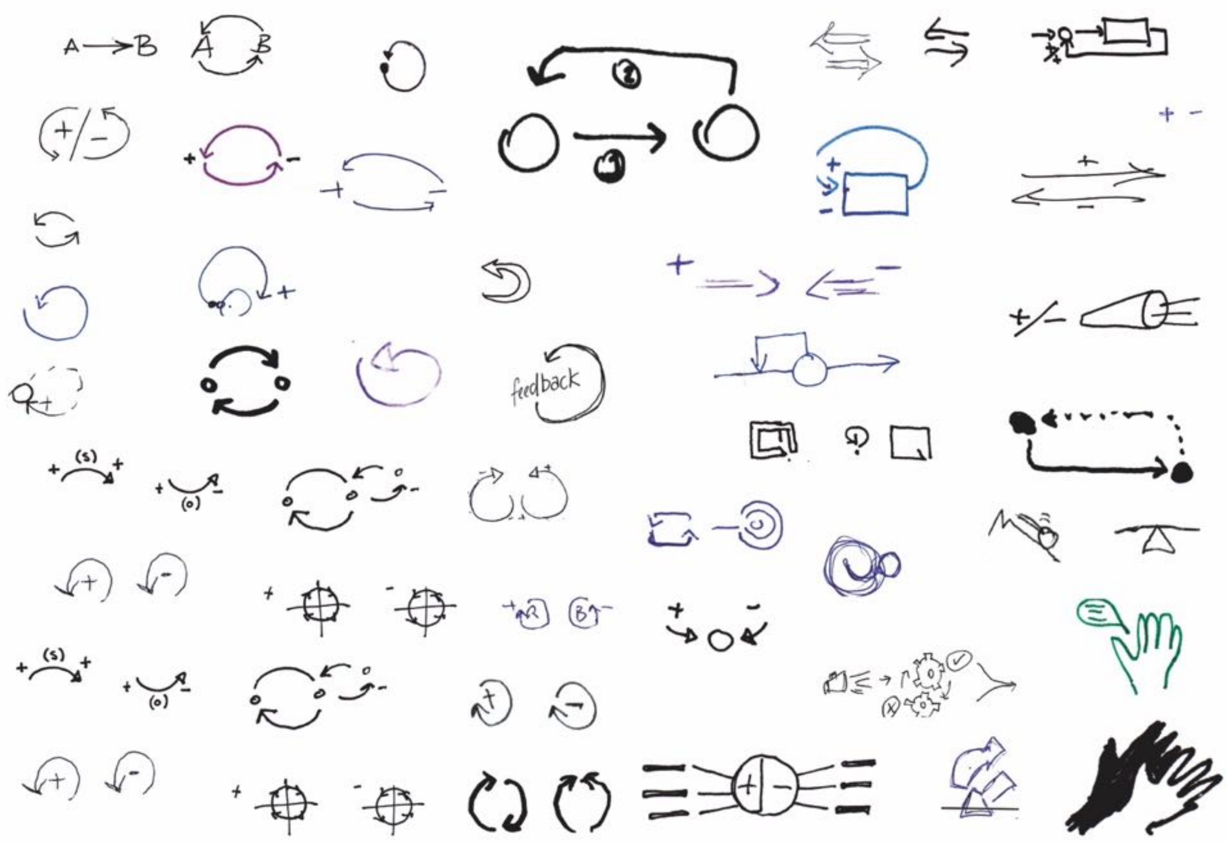


Figure 2. Feedback (positive + negative). Characteristic sheet - collection of RSD6 survey responses.

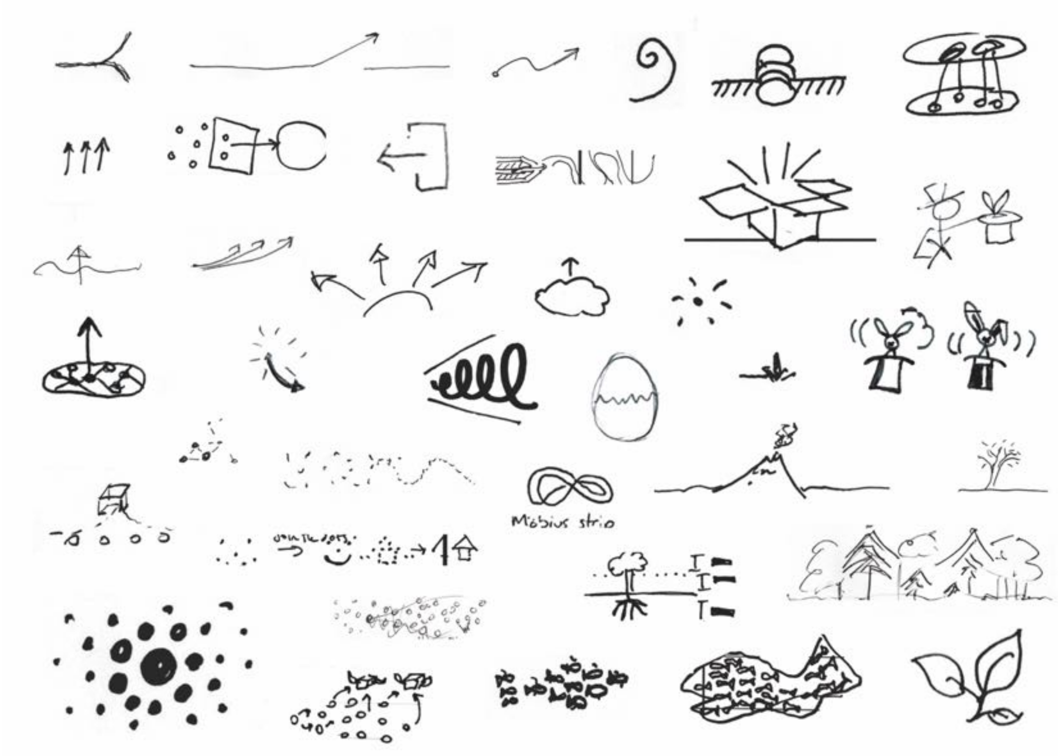


Figure 3. Emergence

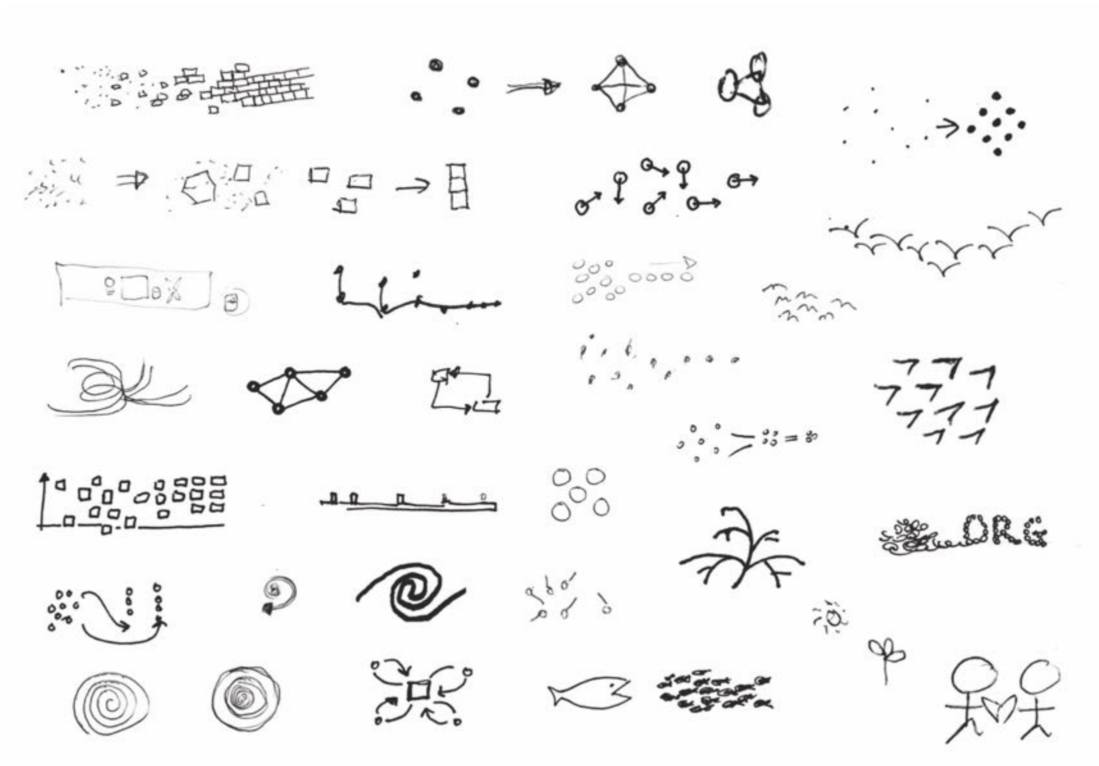


Figure 4. Self-organisation. Characteristic sheet - collection of RSD6 survey responses.

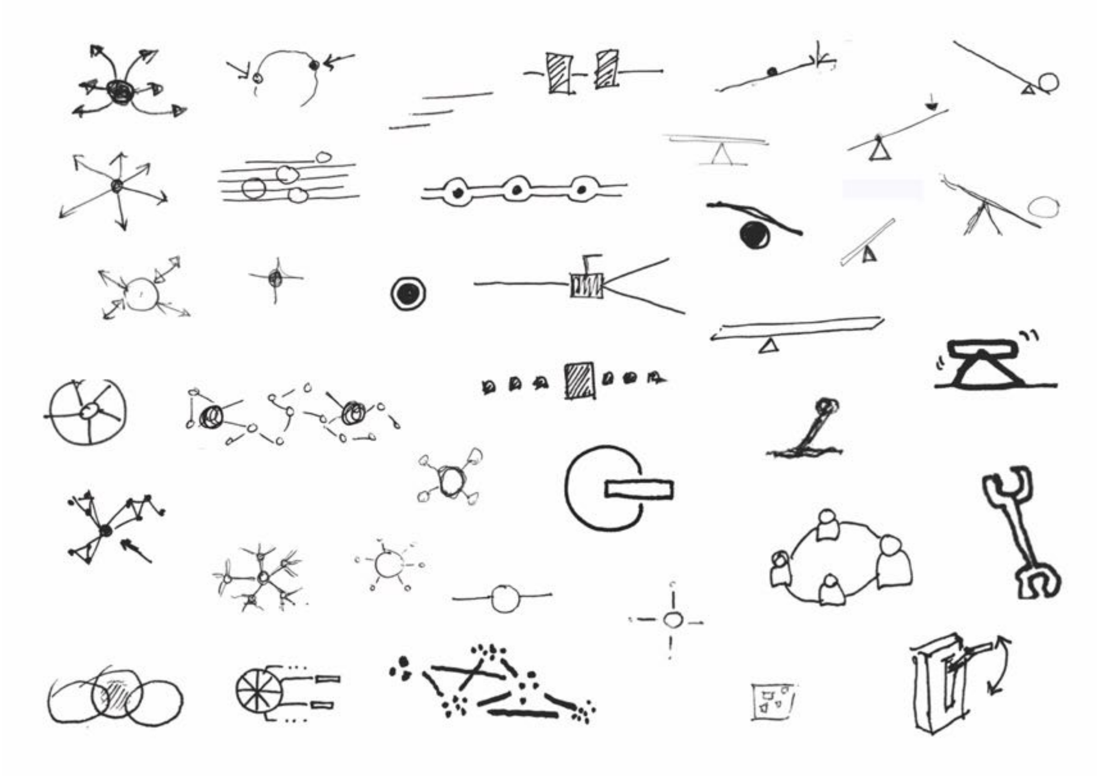


Figure 5. Levers and hubs. Characteristic sheet - collection of RSD6 survey responses.

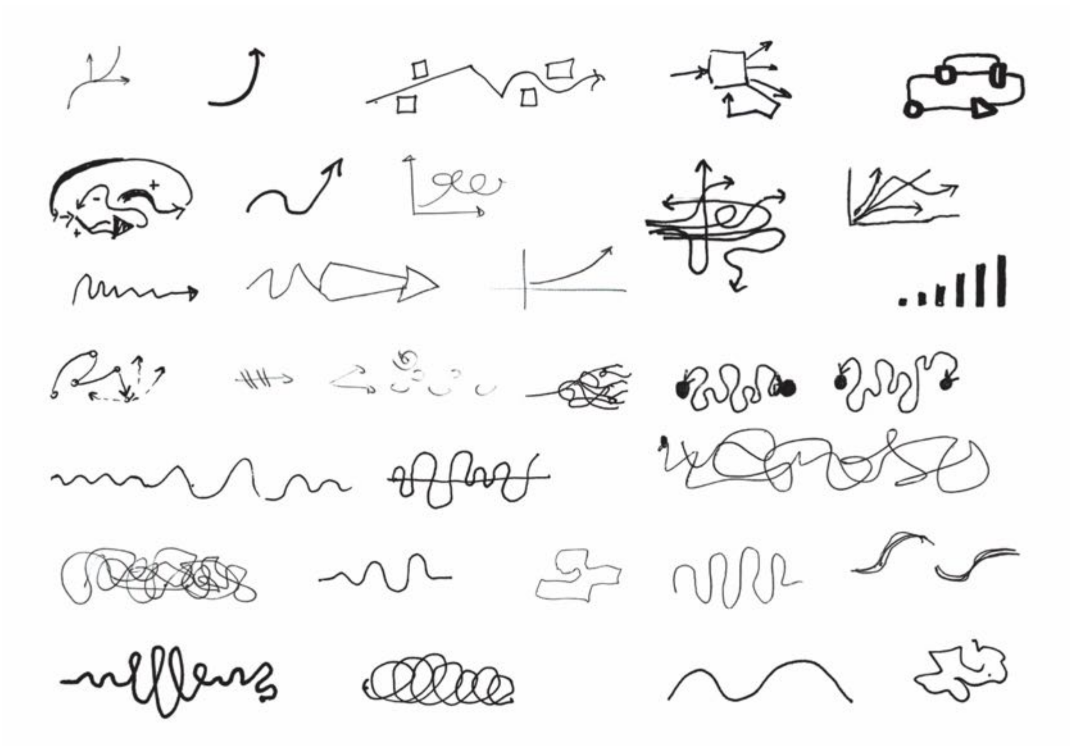


Figure 6. Property non-linearity. Characteristic sheet - collection of RSD6 survey responses.

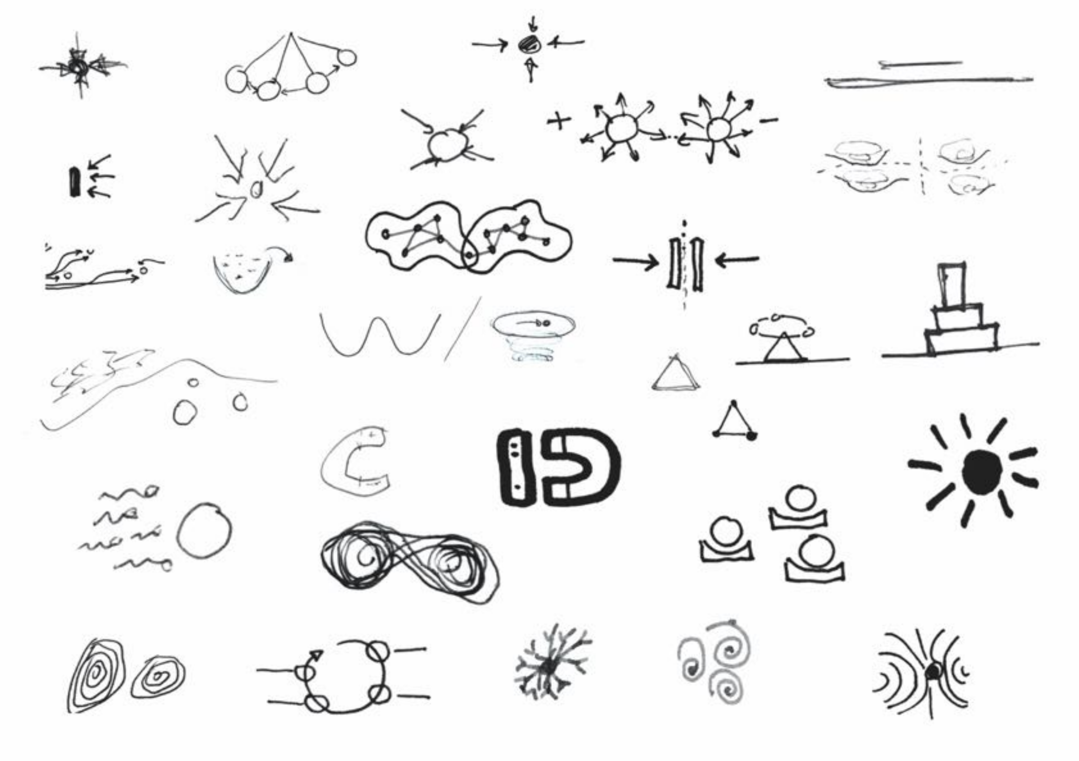


Figure 7. Domains of stability / attractors. Characteristic sheet - collection of RSD6 survey responses.

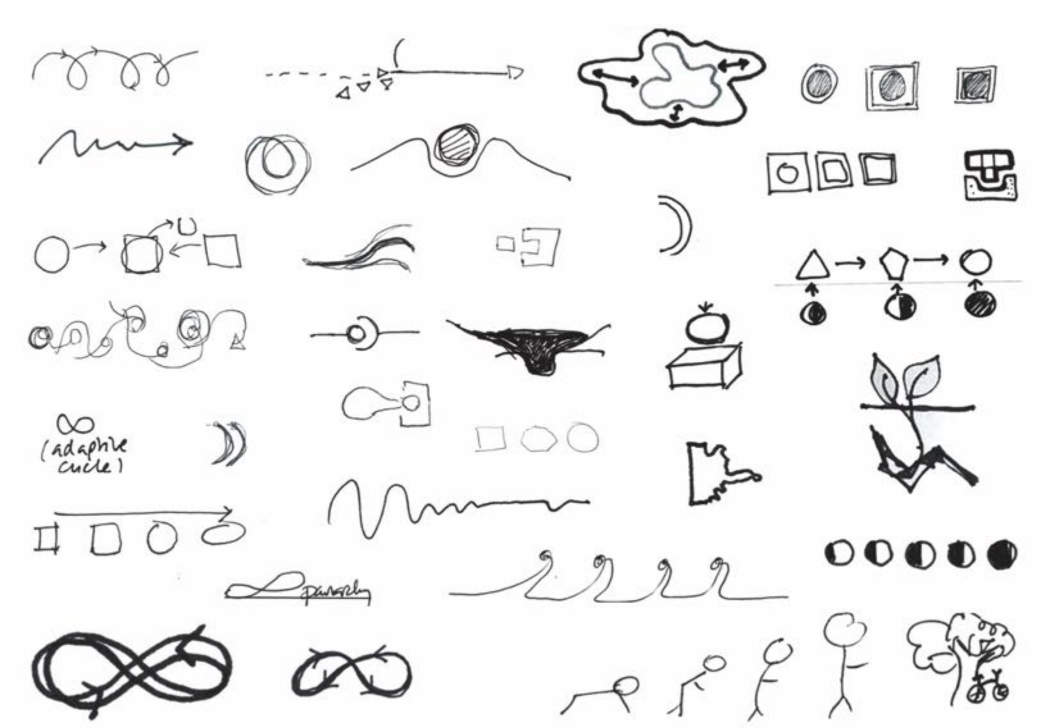


Figure 8. Adaptation. Characteristic sheet - collection of RSD6 survey responses.

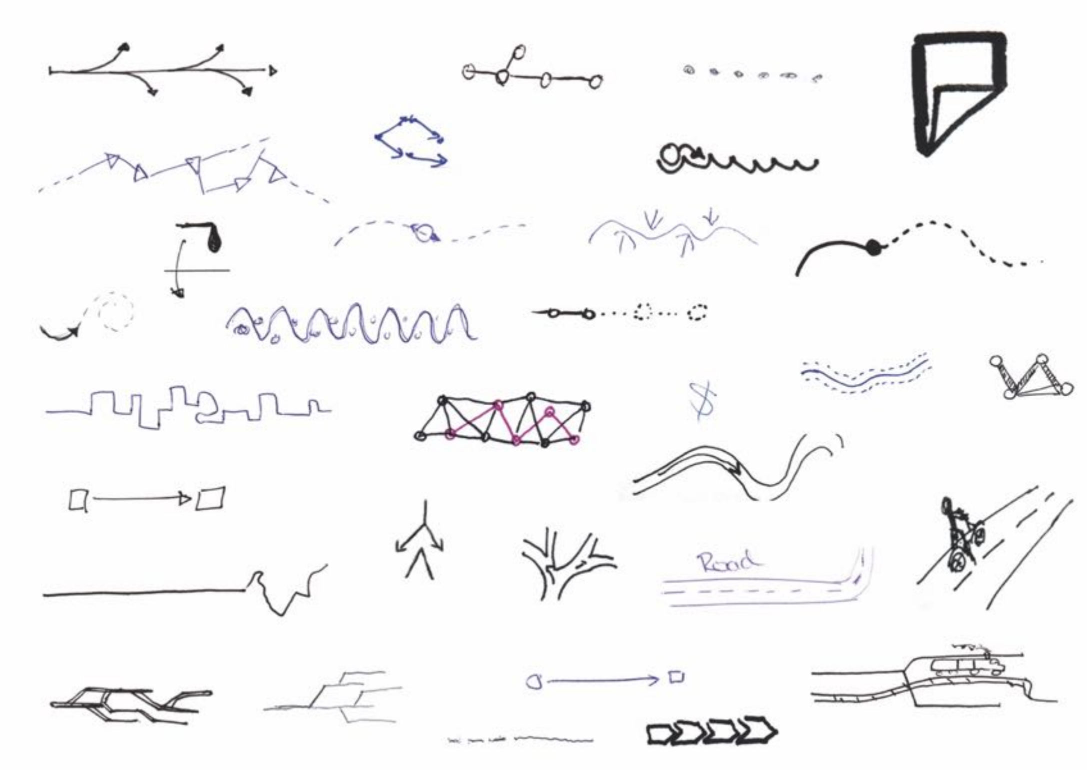


Figure 9. Path + path dependency. Characteristic sheet - collection of RSD6 survey responses.

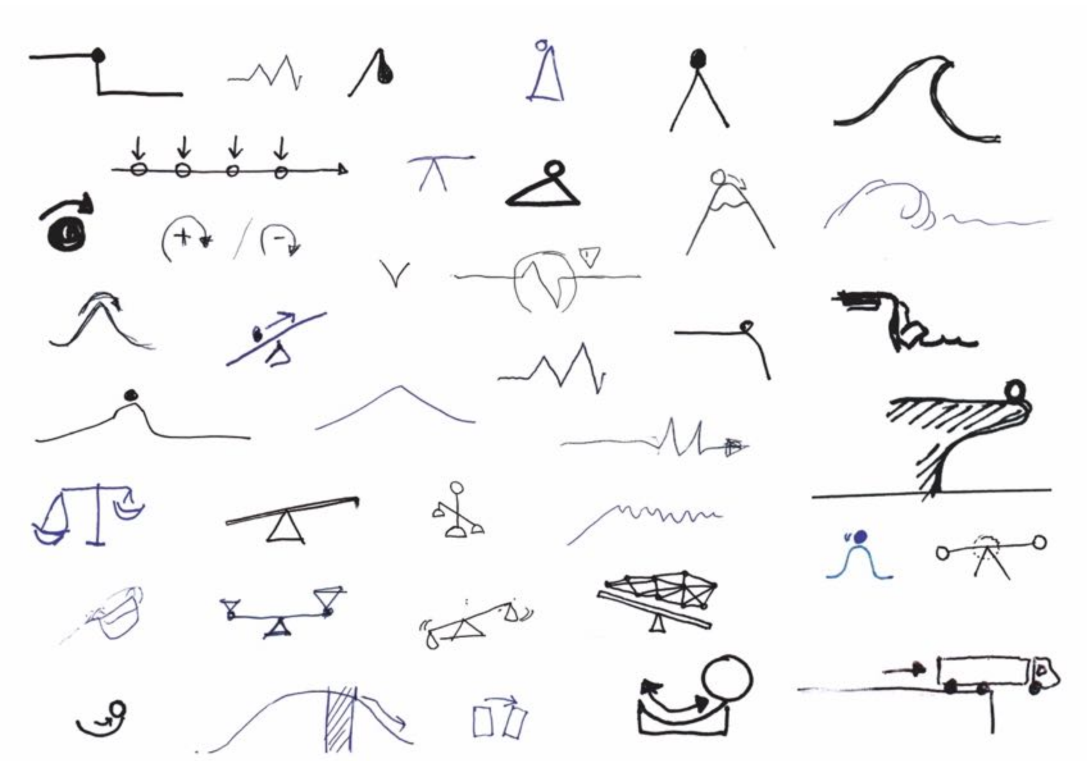


Figure 10. Tipping points. Characteristic sheet - collection of RSD6 survey responses.

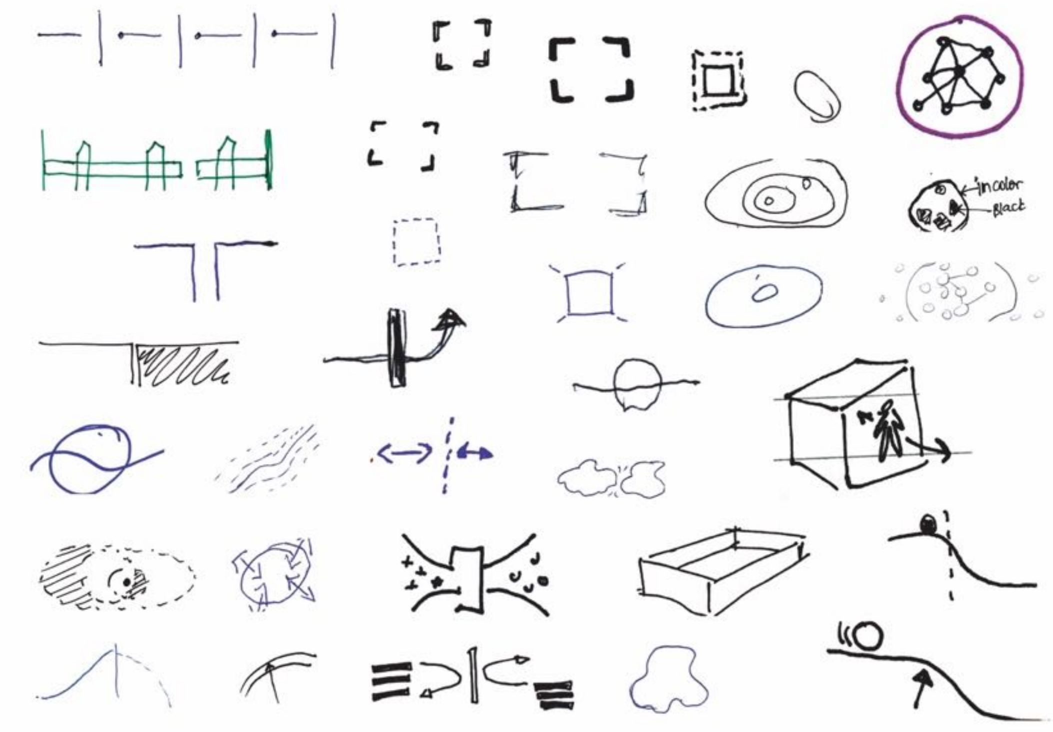


Figure 11. Boundary / Threshold. Characteristic sheet - collection of RSD6 survey responses.

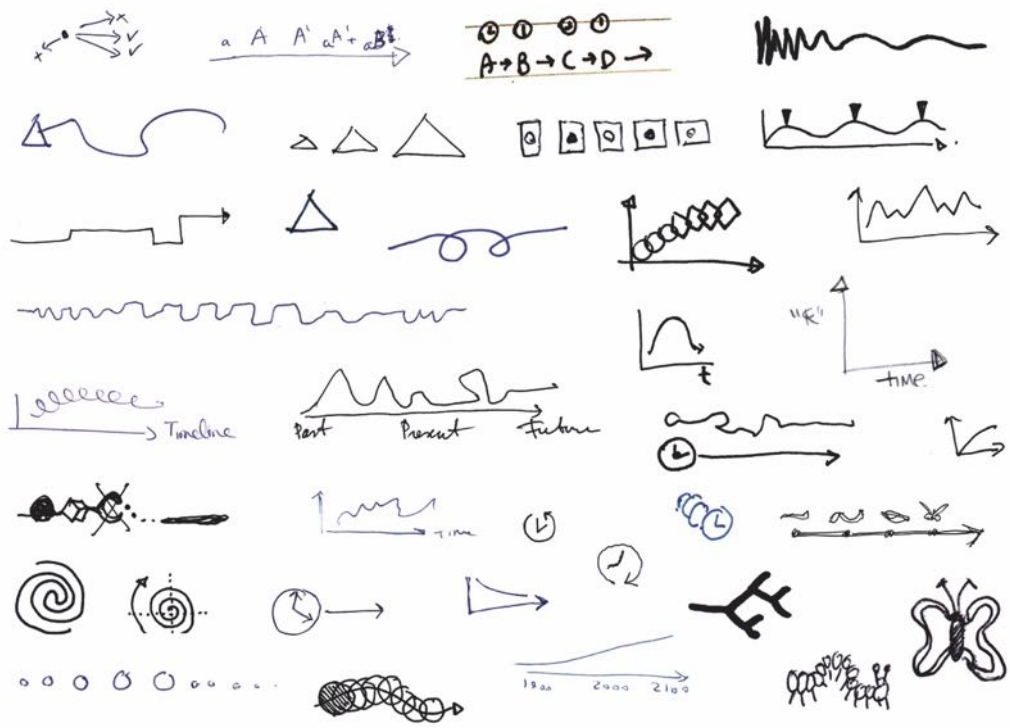


Figure 12. Change over time. Characteristic sheet - collection of RSD6 survey responses.

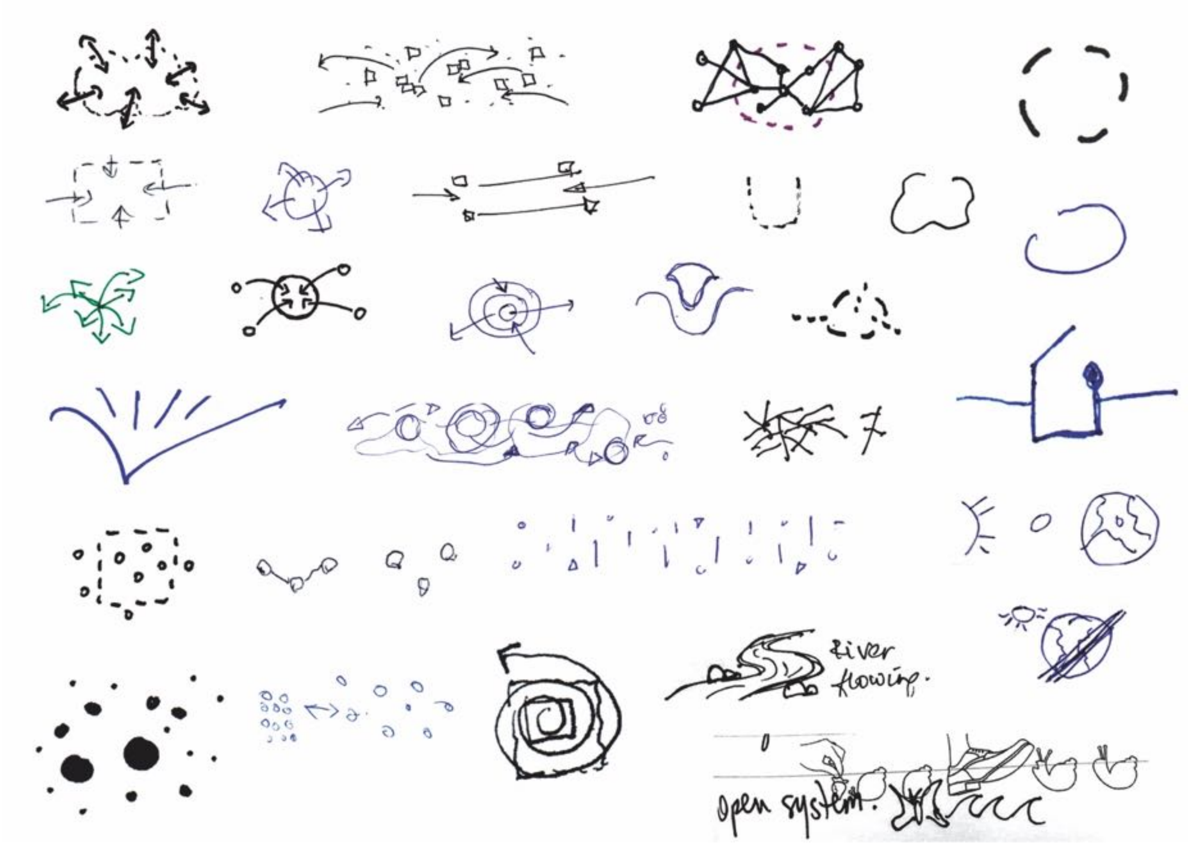


Figure 13. Open system. Characteristic sheet - collection of RSD6 survey responses.

The new characteristic sheets were a basis for the two participatory concept mapping design workshops at the University of Westminster in London with the CECAN research group (November 17 & December 15, 2017). These three-hour workshops gave the research group an opportunity to view results of the survey, deliberate on the results and create new visual outcomes based on new knowledge generated in the discussions. We conducted a design crit on each characteristic sheet. The most popular visual representations were identified and discussed in detail although the group made an explicit decision not to rely on popularity as the basis on which a final graphic would be designed, but rather sought images that captured the essential characteristics of each concept according to group discussions.

The CECAN research group brought their own ideas and images to the project. Everyone contributed sketches and together we developed a variety of visual strategies. In some instances (emergence, adaptation) none of the images collected by the survey results were used as the research group aspired to generate entirely new visual metaphor to capture specific meanings that were insufficiently embodied by any of the images collected in the surveys.

Figure 14. Characteristic sheets at the CECAN workshop, 17 November 2017, University of Westminster.

Figure 15. Change over time sheets at the CECAN workshop, 17 November 2017, University of Westminster.

During the two workshops five more characteristics were identified to make a total of sixteen. The boundary / threshold concept was dropped and five new characteristics were added at this stage (unpredictability, unknowns, distributed control, nested systems and multiple scales). The ideas generated in these workshops were the basis for the generation of the final outcomes over the following three months.

3.4 Representation of Ideas: Design of Visual Outcomes

I was responsible for designing all 16 images as the CECAN research group developed new definitions, examples and learning points over the following months. The sixteen features of complexity visualised by this project are: feedback, emergence, self-organization, levers / hubs, non-linearity, domains of stability, adaptation, path dependency, tipping points, change over time, unpredictability, unknowns, distributed control, nested systems and multiple scales.

3.5 Interpretation of Ideas: Re-Design of Visual Outcomes

As the visualisations for each feature took form, each visualisation was further interpreted by the CECAN research group. Feedback was taken and the visualisations were refined. The design research process was completed in April 2018. The final visual outcomes for each feature are below embedded in the poster (figure 16) which is also available online.

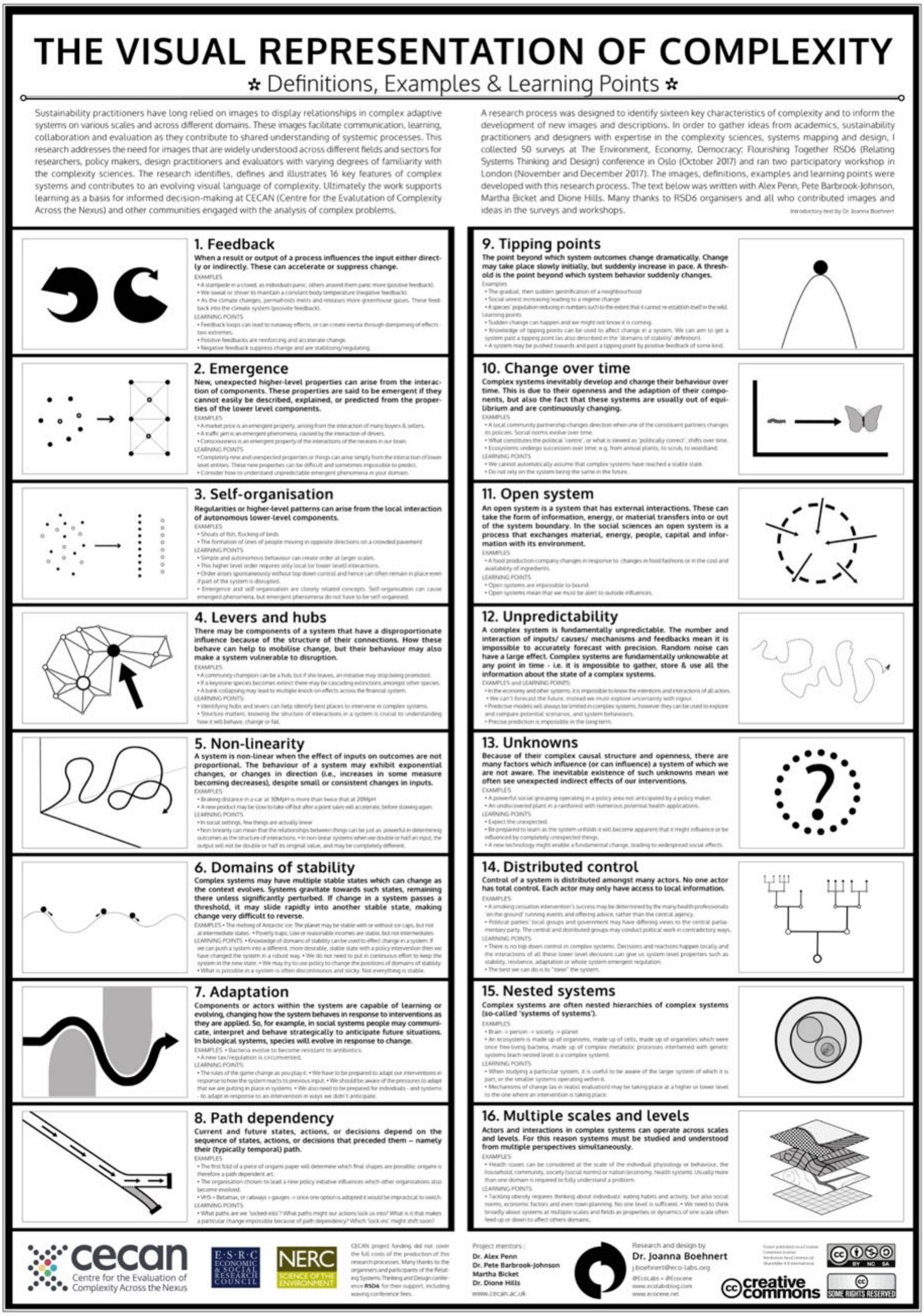


Figure 16. The Visual Representation Of Complexity: Definitions, Examples & Learning Points. A1 poster.

3.7 Ultilisation of Ideas: RSD7 and Beyond

I presented earlier version of this paper at the RSD7 symposium (Challenging Complexity By Systemic Design Towards Sustainability, Turin, October 24-26, 2018) along with the poster (figure 17) at the RSD7 "Visualizing Complex Systems" exhibition. The collection of images from the 50 RSD6 surveys were made available online for other designers and researchers to use for their own purposes. This work has over two hundred interactions on Twitter over the past year.

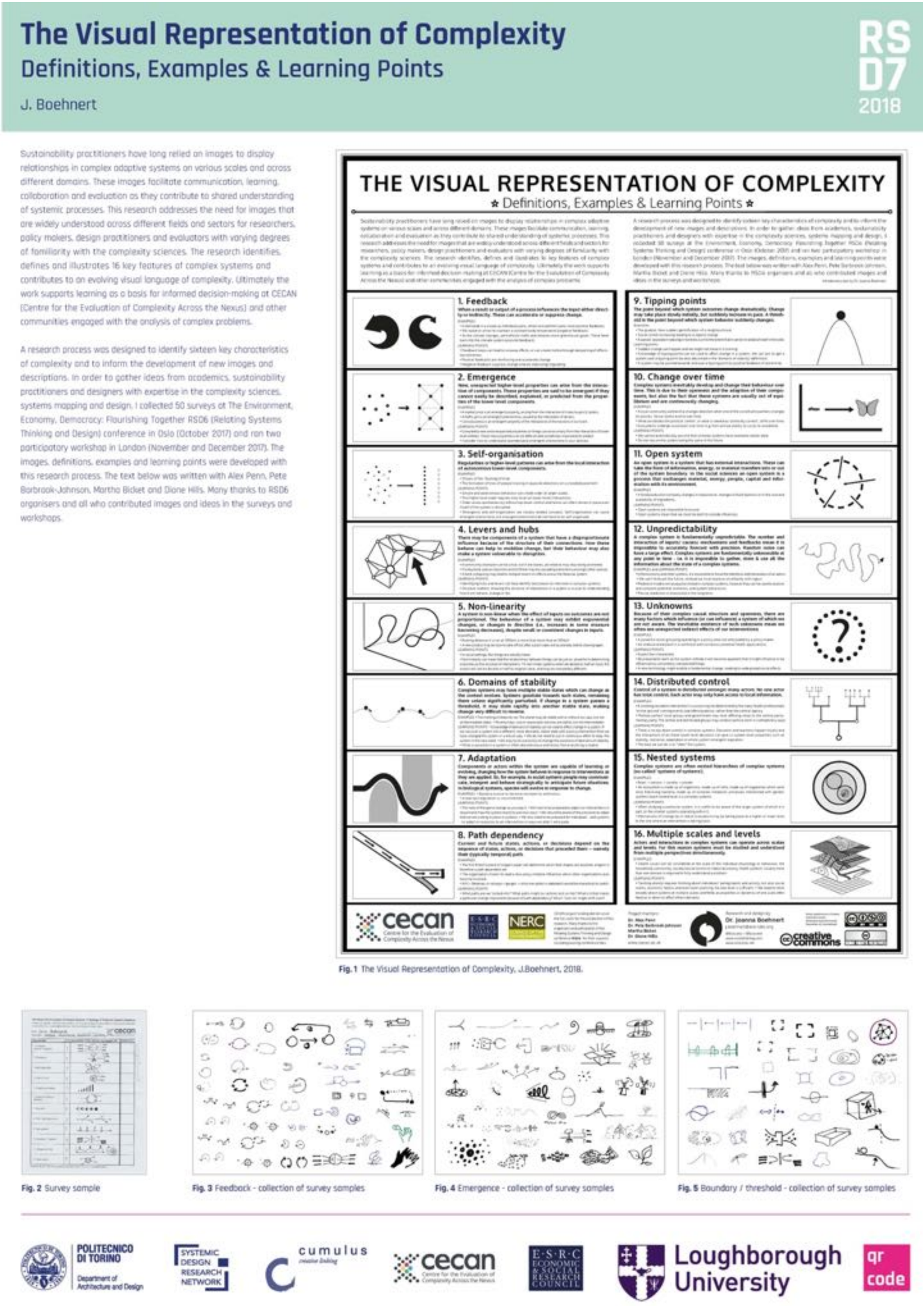


Figure 17. The Visual Representation Of Complexity. RSD7 poster.

4. Reflections

This short research project created space to examine, critically assess and redesign visual representations of some of the key features of complexity with an interdisciplinary research team using a participatory design research process. It brought design knowledge to the CECAN community and expertise from the CECAN research group to the systemic design community engaged with this research. Over the past decade systemic designers have sought to develop visualisation practices to capture complex systemic processes. Images can provide a nuanced understanding of systemic processes and serve to nurture relational ways of understanding complex phenomenon by displaying information about the features and types of relationships (Sevaldson 2016; Boehnert 2014, 2018). This visual representation of relationships as a means of supporting relational perception and ecological perception (Sewall 1995, 1999; Boehnert 2014, 2018). Since complexity is often characterized by relationships, i.e. it is the dynamics between different actors that determines how system functions, relational perception can a means of understanding complexity.

This research project was made significantly more difficult by the way CECAN management engaged with the design research process. Participatory design processes often face the common problem of scope creep as work expands with the involvement of people pulling in different directions, accelerated by the power imbalances between participants. The initial research proposal for this research was very different from the ideas that were developed for the outcomes once participatory processes were initiated. The additional work generated by requests for new illustrative icons (not codes) and then entirely new visualisations were not supported by CECAN management despite my request to be paid for the work of attending to new objectives.

Despite these difficulties, this research was completed to inform decision-making at CECAN and other communities engaged with the analysis of complex problems. The identification of 16 key characteristics with definitions, learning points, examples and illustrations can be used as a learning resources for practitioners, academics and students alike. The work supports learning, collaboration and decision-making for interdisciplinary researchers, policy makers, design practitioners and evaluators as we develop a shared understanding of systemic processes. The research contributes new definitions and visual representation of key features of complexity.

Acknowledgements

Many thanks to the organisers and participants of RSD6 Oslo and the CECAN research group (Alex Penn, Pete Barbrook-Johnson, Martha Bicket and Dione Hills) for their contributions to this work. This research project was completed with the support of Loughborough University.

References

Boehnert, J. (2014). Ecological Perception: Seeing Systems. In Proceedings of DRS 2014: Design's Big Debates, Umea, Sweden, 16–19 June.

Boehnert, J. (2017). CECAN Fellowship application form (unpublished).

Boehnert, J. (2018). *Design, Ecology, Politics: Towards the Ecocene*. London: Bloomsbury Academic.

Cabrera, D. & Trochim, W.M.K. (2006). A Theory of Systems Evaluation, in *Systems Evaluation and Evaluation Systems Whitepaper Series*. Ithaca, NY: Cornell University Dspace Open Access Repository.

Cabrera, D. (2008). Distinctions, Systems, Relationships, Perspectives: The Simple Rules of Complex Conceptual Systems: Proceedings of the 52nd Annual Meeting of the ISSS, Jan 1, 2008.

Gell-Mann, M. (1995/96). Let's Call It Plectics. *Complexity*, 1 (5), John Wiley and Sons, Inc.

Greene, J. C., & Caracelli, V. J. (1997). Advances in mixed-method evaluation: The challenges and benefits of integrating diverse paradigms. In J. C. Greene & V. J. Caracelli (Eds.), *New directions for program evaluation* (Vol. 74). San Francisco, CA: Jossey-Bass.

Jones, P.H. (2014). Systemic design principles for complex social systems. In G. Metcalf (ed.), *Social Systems and Design,* Volume 1 of the Translational Systems Science Series, pp 91-128. Springer.

Jones, P. (2014) RSD3/ Relating Systems Thinking and Design 2014. Design Research Methods in Systemic Design In Proceedings of RSD3, Third Symposium of Relating Systems Thinking to Design.

Masud, L., Valsecchi, F., Ciuccarelli, P., Ricci, D., & Caviglia, G. (2010). From Data to Knowledge Visualizations as Transformation Processes Within the Data-Information-Knowledge Continuum. 14th International Conference Information Visualisation (26-29 July) London, United Kingdom.

Sevaldson, B. (2013). "Systems Oriented Design: The Emergence and Development of a Designerly Approach to Address Complexity." In Proceedings of DRS/Cumulus Oslo 2013: 2nd International Conference for Design Research Education Researchers. Oslo: DRS/Cumulus (May 2013): 1-22.

Sevaldson, B. (2016). A Library of Systemic Relations. SOD. Accessed online: http://www.systemsorienteddesign.net/index.php/giga-mapping/types-of-systemic-relations

Sewall, L. (1995). The Skills of Ecological Perception. In T Roszak, M Gomes, & A Kanner (eds.) *Ecopsychology.* San Francisco, CA: Sierra Club Books, 201–215.

Sewall, L. (1999). *Sight and Sensibility: The Ecopsychology of Perception*. New York, NY: Putnam.

Trochim, W. (1989). An introduction to concept mapping for planning and evaluation. *Evaluation and Program Planning*, 12(1), 1-16.

Trochim, W. & Cabrera, D. (2005). The Complexity of Concept Mapping for Policy Analysis. Prepared for the 1st International Workshop on Complexity and Policy Analysis, Cork Ireland, 22-24 June 2005.