Complex Network Visualizations as a Means of Generative Research in Design

Andre Murnieks, University of Notre Dame, United States

The search for a possible design question, or generative research, is problematic. Generative research in design often relies on an unseen, intangible spark of intuition that leads to a novel design approach, and not many scholars or clients appreciate (or trust) the abstract nature of this process. Gathering information like demographics is useful data, but it only provides comparative information. Though charts and graphs can make apparent what is already true in the numbers, they cannot reveal much more than that. They cannot, for example, reflect how a user population behaves, interacts, socializes, or moves. Consequently, the ways in which we navigate our world though visual communication, electronic or otherwise, is an increasingly challenging design problem. Seeing clear patterns for behavior is especially important in interaction design. Visual representations of pattern phenomena are possible with network science. The United States National Research Council defines network science as "the study of network representations of physical, biological, and social phenomena leading to predictive models of these phenomena." (Wikipedia, 2013). Most visualizations of complex networks are literally represented as lines connecting dots, the dots as data points and the lines as relationships. Carefully choosing the best data points, based on meaningful relationships, and applying good information design technique, makes a more comprehensive view of a designated design problem possible. A network visualization can be dynamic and three dimensional, though meaningful compositional view of a two-dimensional model can suffice. Because the data are visual, design decisions are more clearly communicated to both the designer and her audience. While it is possible to analyze the complex network with various mathematical functions—like density, clustering and connectedness—through these types of visualizations, a few simple examples show how powerful network science models can be.

Keywords: Generative Design Research, Complex Network Science, Data Visualizations, User Behavior, Data Analysis

A Matter of Tastes

Consider gathering the ingredient lists of popular recipes and the flavors produced when those ingredients combined in different dishes. Connect the various associations between ingredients and weight them for frequency—plus some math to help it along. The result is a "flavor network" that could predict, or help *design*, new dishes proposed in a paper entitled *Flavor network and the principles of food pairing*.[1] The network also reveals cultural differences for taste between North American dishes and East Asian cuisine. The authors do not explicitly state it, but Americans skew towards bland: milk, wheat, butter, egg, vanilla, and cane molasses.

Now consider combining the music recommendation engines of AllMusicGuide, Amazon, Launch-Yahoo!, and MSN Entertainment into a model that basically merges playlists, expert recommendations, and purchase history to discover both popular and obscure music that may appeal to the listener as described in a research paper entitled *Topology of music recommendation networks*.[2] The web of interconnectedness of the combined datasets can create more and longer paths, or long tails, to desirable music. In other words, it could recommend music at a larger degree of separation—as in Kevin Bacon. Again, behind the science is a good amount of math. More importantly, to predict either new dishes or good music, a good deal of existing data must be collected and structured in a manner to allow for such discoveries. Both examples utilize network science to describe a structure of relationships among the data points to create a visualization that may show actionable patterns—patterns that a design researcher could apply in her work.

[1] Ahn, Yong-Yeol et al. "Flavor network and the principles of food pairing." *Scientific reports* 1 (2011).
[2] Cano, Pedro et al. "Topology of music recommendation networks." Chaos: An Interdisciplinary Journal of Nonlinear Science 16.1 (2006): 013107.

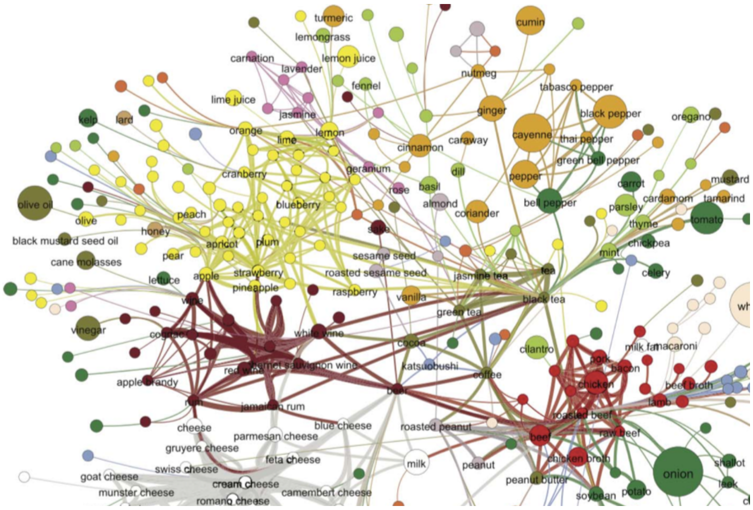

Figure 1: A visual portion of the flavor network

Source(s): Ahn 2011

Network Science as Design Research Methodology

Let us begin with an endorsement and a disclaimer. In the summer of 2012, Arts, Humanities, and Complex Networks — 3rd Leonardo satellite symposium, as part of the larger international NetSci conference, convened at Northwestern University with a mission…

> "…to highlight arts and humanities as an interesting source of data, where the combined experience of arts, humanities research, and natural science makes a huge difference in overcoming the limitations of artificially segregated communities of practice.
>
> "Furthermore, the symposium will focus on striking examples, where artists and humanities researchers make an impact within the natural sciences. By bringing together network scientists and specialists from the arts and humanities we strive for a better understanding of networks and their visualizations in general." [3]

From this, one would expect that two things would be apparent: 1. Designers and artists can work with network scientists to make visualizations more effective, and 2. Network science can be applied to topic areas the arts and humanities to generate new knowledge from seemingly disconnected, qualitative data. Both symposium objectives were realized in the papers and demonstrations presented. Additionally, if one is viewing the work through eyes of a visual communication design researcher and problem solver, one could not help seeing another application. In each of the opening examples, scholarly research drives the network scientist to explore a question and yield her results, while the designer views the work product of the scholar's research as potential data for a design project as applied research.[4] In the example concerning music tastes, the designer might be charged with improving on a social media platform for music and is seeking ways in which to innovate. The discovery of better ways to connect music lovers with their music

---

[3] "Arts, Humanities, and Complex Networks – 3rd Leonardo satellite symposium - NetSci2012." 2012. 16 Feb. 2014 <http://artshumanities.netsci2012.net/>

[4] Brown, B., Gough, P. and Roddis, J. (2004) Types of Research in the Creative Arts and Design [online]. Bristol, UK: E-Papers, University of Brighton.

could influence design decisions with regard to the user experience. The network science algorithms coupled with the designed delivery platform could be a differentiating advantage for a product in the marketplace.

While promising, the process described will require the expertise of a network scientist. The picture painted in Figure 1 appears relatively easy from which to read and draw conclusions, but the casual viewer cannot make any assumptions that are not backed up by statistical analysis. Nor can the mathematical algorithms guiding the formation of the visualizations be underestimated in their domain-specific complexity. Therefore, the information discussed here is meant to introduce the design researcher to the potential of network science visualizations as a means to generate questions, and to leave the validity of the experiments to the experts.

Finding an Answer in a Complex Network

Before breaking down complex network visualizations further, a simple example is offered in Figure 2 to demonstrate a real problem at least for instructors: the pairing of students into project groups. The resulting network visualization helps team everyone (nearly). Each student in class is asked to privately select her top two to three choices for a project partner; one of the choices may be "anybody" indicating a willingness to work with anyone. Each of these pairings is added as a record to an elegant web-based tool called Graph Commons by Burak Arıkan. Arikan demonstrated this tool during his keynote at Arts, Humanities, and Complex Networks.[5] Graph Commons creates "vertices" or "nodes" from each of the unique students' names and adds "edges" to represent, in this case, partner choices.

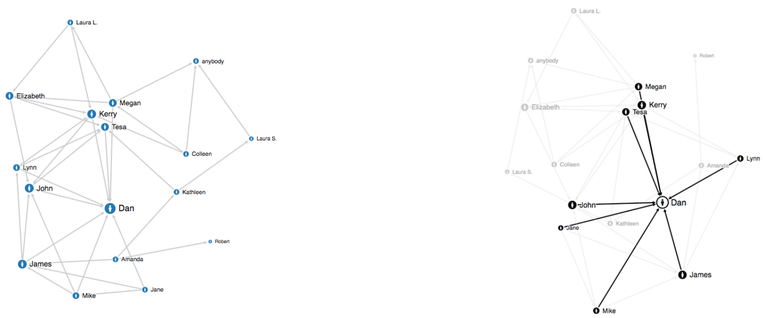

Figure 2: A network of student's three choices for studio partner

Source(s): Ahn 2011

The resulting "lattice" created visualizes the dynamics of the choices of each of the student nodes. Those preferred as partners more (Dan, John, James, Kerry, and Elizabeth) are automatically labeled as "central nodes." The software automatically deems them as the beginnings of "clusters" because they have a greater number of edges directed at them, and they also appear bigger. The node "Robert" was absent the day the partner preferences were submitted, but luckily node "Amanda" made him a choice, otherwise he would have been a disconnected outlier. The effort to find sets of partners that fit with the desires of the students and some conscious choices made by the instructor not to pair certain individuals is made far easier with the network visualization. Beyond the sheer utility, the data may indicate other traits for the nodes like perceived competency in the course, popularity, or perhaps other interests? Anecdotally, the central nodes

5 "Burak Arikan » Keynote at Arts, Humanities, and Complex Networks ..." 2012. 16 Feb. 2014 <http://burak-arikan.com/keynote-at-arts-humanities-and-complex-networks-conference-netsci2012-chicago>

("popular students") finished the previous project quite successfully which could be adding to their desirability as project partners.

Formulating a Design Question

More often than not, designers join the development phase of a project after the primary research is completed. Strategy is passed along from the gatekeepers of this information, and the design team is charged with interpreting the data. Everyone involved hopes that it manifests itself somehow in the final product. Even so, the data gathered is often demographics, market analysis, and benchmarking that do little but to validate the original, preconceived design direction that existed at the onset of the project. We already have asked and answered the question; now it is just a matter of building it.

Generative Research

Finding a solution to a design problem is often daunting, but what if the design researcher can help find the design problem? Generative research in design is the phase at which the questions are being asked and the problem is yet to be defined. Liz Sanders in her paper *An Evolving Map of Design Practice and Design Research* defines both critical and generative design's aim to "to generate and promote alternatives to the current situation."[6] Sanders is specifically referring to a participatory exercise involving typical end-users in the design process. Another of a possible form generative research is IDEO's "deep dive" that favors a more human-centered, ethnographic approach to gain insight about end-users needs and desires.[7] Both methods are gathering data, albeit unstructured; and both rely heavily on perceived and intuited patterns of behavior or insights. Plus, the sample population is generally low.

Network visualization can enhance other types of generative research by juxtaposing a focused, participatory study against a network model that could express hundreds, thousands or even millions of data points in a meaningful way. Does data already exist that can lend itself to a network model? Perhaps the strategists are handing over applicable data that can be graphed with a method other than a pie chart? Then there is a caveat: the data must lend itself to the structure of vertices and edges.

Potential Data Types

If the visualization is going to reveal any kind of structure, the collected data must have relationships that can be exposed. The potential topics may sound narrow, but the range of application to real-world situations is diverse: food webs, electrical power grids, cellular and metabolic networks, the World-Wide Web the Internet backbone, the neural network of the nematode worm *Caenorhabditis elegans*, telephone call graphs, coauthorship and citation networks of scientists, and the quintessential 'old-boy' network, the overlapping boards of directors of the largest companies in the United States as noted in the article by Steven Strogatz entitled *Exploring complex networks*.[8]

The kinds of relationships studied are physical, behavioral, conceptual, and community based. In his paper entitled *The "New" Science of Network*s, Duncan Watts summarizes the classes (or motifs) of network diagrams: 1. networks that process information (logic), 2. networks that process energy (flavor network), 3. networks that symbolize communities of knowledge (www). Though he is not certain how social networks should be classified. This opens up a wide

[6] Sanders, Liz. "On Modeling: An evolving map of design practice and design research." interactions 15.6 (2008): 13-17.
[7] "Deep-Dive brainstorming technique – IDEO - RapidBI." 2012. 16 Feb. 2014 <http://rapidbi.com/deep-dive-brainstorming-technique-ideo/>
[8] Strogatz, Steven H. "Exploring complex networks." *Nature* 410.6825 (2001): 268-276.

range of applications for the design researcher, and it is simply a matter of framing the research question. In the example from Figure 2, the motif appears to be a social network, but it is more likely a logic network because it is processing the puzzle of whom to team with whom. In a sense, it is visually depicting the rules to the game set by the players themselves.

Power of Data Visualization

In Figure 3, A Periodic Table of Visualization Methods[9] groups the various graphic methods for rendering data into a handy chart. It is a web-enabled, interactive chart that allows the user to rollover each method, from "continuum" to "spray variable," and see examples—though not the most designerly of examples. This chart represents the toolbox of the means in which research data is communicated and a huge opportunity for visual communication design.

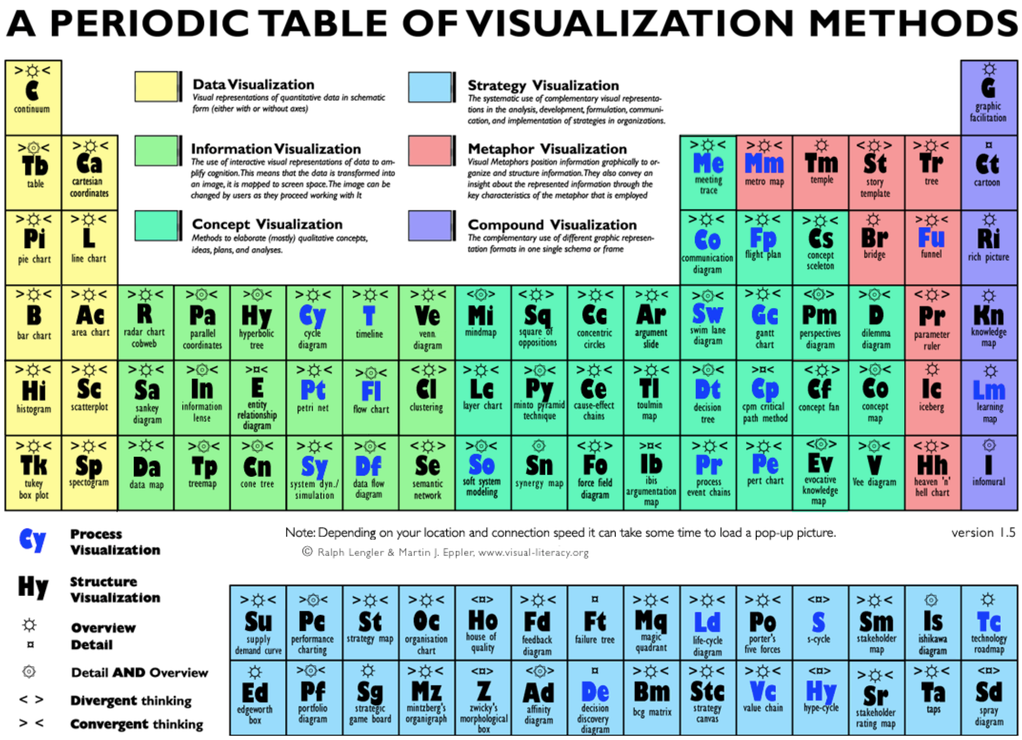

Figure 3: A Periodic Table of Data Visualization Methods

Source(s): visual-literacty.org 2014

Designers are probably the wrong audience to convince that the design of information is important. It seems obvious, but yet the various research and scientific communities keep churning out meaningful data in the least aesthetic forms possible. Are designers that difficult to work with? Is the underlying science that difficult? Yet the need for design in this area is becoming

[9] "A Periodic Table of Visualization Methods - Visual Literacy." 2007. 16 Feb. 2014 <http://www.visual-literacy.org/periodic_table/periodic_table.html>

more important. The very nature of a complex network is vastly more complicated to visualize than a typical pie chart because it is meant to summarize thousands of data points. When the dataset is so large, visualization may be the only way to make and sense of it:

> "Data visualization combines data and design to give insight and understanding to complex issues." —Adam Bly[10]

> "Visualizations are absolutely critical to our ability to process complex…in presenting scientific results, particularly outside of a traditional scientific context, these visualizations can be extremely powerful, but they generally require creative or artistic efforts that are beyond the range of current computational capabilities." —Peter Fox and James Hendler[11]

Building a Complex Network without a Network Scientist

Like the previous example Graph Common used in Figure 1, there are other freely distributed, open source software to help create complex network visualizations. In the process of writing this paper, the following software titles were discovered: Cytoscape (cytoscape.org), Tulip (tulip.labri.fr/TulipDrupal), Graphviz (graphviz.org), Gephi (gephi.org), Pajek (pajek.imfm.si), NodeXL (nodexl.codeplex.com), and Graph Commons (graphcommons.com). As it said in many papers, more research is needed to discover unique abilities or ease-of-use of each of these software packages, and whether the nonscientist is able to utilize any of these capabilities.

Why a Complex Network Visualization?

Design researchers need tools that reach beyond anecdotal evidence, heuristic evaluation, weak surveys, and the information that comes out of strategy reports. These sources may be useful, but all research is better if multiple methods are employed.[12] Beyond good design practice, complex network science visualizations have some appealing features. They may be dynamic and interactive responding to user input allowing the viewer drag vertices and revolve the model to get a better view. As in the example shown in Figure 1, the visualization can change as the viewer clicks on certain nodes and relevant data are exposed, while other parts of the model are occluded. A complex network may also be based on an ever-changing large data set that exists in the cloud or aggregated from multiple sources on the web. This means the data can constantly change and the model will be updated to reflect those changes—instantly.

> "Despite the increasing prevalence of these techniques on the Web, we are often looking at tables of numbers, best-fit curves, or other analytic results rather than being able to use visual means when we interact with the complex scientific data in many fields. Many of the visualization tools that are available to scientists do not allow live linking as do these Web-based tools. Once the visualization is created, it is no longer tied to the data, so that it becomes an immutable information product—as the data changes, the visualization is no longer up to date." —Peter Fox and James Hendler[13]

Sharing the sources of design inspiration and the results of costly research are also paramount in academia and in the professional design world. Another advantage of a complex net-

---

[10] "Gaining Understanding from Data Visualization | World Economic ..." 2011. 16 Feb. 2014 <http://www.weforum.org/videos/gaining-understanding-data-visualization>

[11] Fox, Peter, and James Hendler. "Changing the equation on scientific data visualization." Science (Washington) 331.6018 (2011): 705-708.

[12] Zeisel, John. Inquiry by design: Tools for environment-behavior research. CUP Archive, 1984.

[13] Ibid.

work visualization is that it is possible for the layperson to see the results of the research in a compelling format. As a fringe benefit, the visualization can be quite beautiful especially as the density of the information increases.

And most importantly, the process may reveal a design opportunity that would have never have been considered. Somewhere in the clustering of the vertices and edges, a new insight about the way a system works or people behave is discovered. This discovery will be the basis of an actionable design endeavor. As a final example to illustrate a possible opportunity for design, Figure 4 is a single frame from an animation that is part of an article from the New England Journal of Medicine entitled *The Spread of Obesity in a Large Social Network over 32 Years.*[14] The visualization supports a key finding represented in a longitudinal study that suggests that obesity can also spread through social ties with others that are obese or exhibit patterns of behavior that would lead to obesity. While "these findings have implications for clinical and public health interventions,"[15] perhaps design researchers, educators, and professionals have a role to play if they can understand the underlying factors.

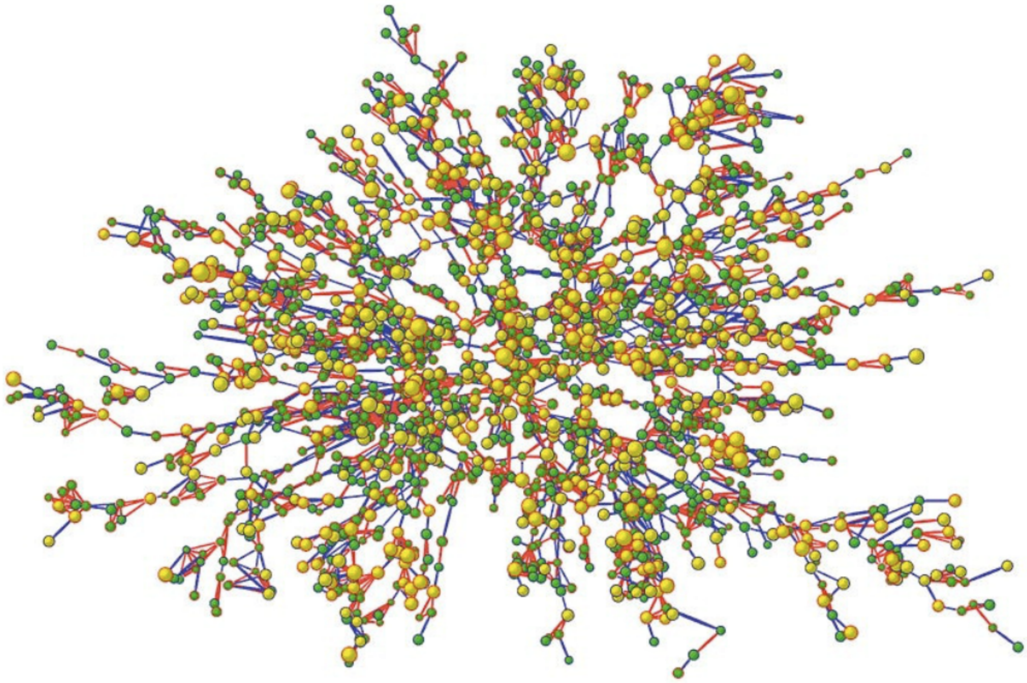

Figure 4: Largest Connected Subcomponent of the Social Network in the Framingham Heart Study in the Year 2000.

Source(s): www.nejm.org/doi/full/10.1056/NEJMsa066082 2014

[14] Christakis, Nicholas A, and James H Fowler. "The spread of obesity in a large social network over 32 years." *New England journal of medicine* 357.4 (2007): 370-379.
[15] Ibid

REFERENCES

Adam Bly: PLANTING A NEW SEED.(seed magazine)(brief article). (2002). *Maclean's,* , 27.
Ahn, Y., Ahn, S., Ahnert, J., & Bagrow, A. (2011). Flavor network and the principles of food pairing. *Scientific Reports, 1* doi:10.1038/srep00196
Arikan, B. (2012). Keynote at arts, humanities, and complex networks conference, NetSci2012, Chicago. Retrieved February 16, 2014, from http://burak-arikan.com/keynote-at-arts-humanities-and-complex-networks-conference-netsci2012-chicago
Brown, B., Gough, P. & Roddis, J. (2004). Types of research in the creative arts and design. Retrieved February 16, 2014, from http://arts.brighton.ac.uk/__data/assets/pdf_file/0003/43077/4_research.pdf
Cano, P., Celma, O., Koppenberger, M., & Buldu, J. M. Topology of music recommendation networks. *CHAOS; Chaos, 16*(1)
Christakis, N. A., & Fowler, J. H. The spread of obesity in a large social network over 32 years. *NEW ENGLAND JOURNAL OF MEDICINE; N.Engl.J.Med., 357*(4), 370-379.
Fox, P. (2011). Changing the equation on scientific data visualization. *Science, 331*(6018), 705-708. doi:10.1126/science.1197654
Jana, R. (2007). TOOL: PERIODIC TABLE OF VISUALIZATION METHODS.(graphics online tool)(brief article). *Businessweek,* (4049), 3.
Jusufi, I., Jusufi, Y., & Dingjie, A. (2010). *The network lens: Interactive exploration of multivariate networks using visual filtering* doi:10.1109/IV.2010.15
Lengler R., E. M. (2007). Towards a periodic table of visualization methods for management. Retrieved February 16, 2014, from http://www.visual-literacy.org/pages/documents.htm
Matei, S. (2011). Analyzing social media networks with NodeXL: Insights from a connected world by Derek Hansen, Ben Shneiderman, and marc A. smith. *International Journal of Human-Computer Interaction, 27*(4), 405-408. doi:10.1080/10447318.2011.544971
Milo, R. (2002). Network motifs: Simple building blocks of complex networks. *Science, 298*(5594), 824-827. doi:10.1126/science.298.5594.824
Network science: Theory and applications. (2009). *M2 Presswire,*
Sanders, L. (2008). ON MODELING An evolving map of design practice and design research. *Interactions, 15*(6), 13-17. doi:10.1145/1409040.1409043
Scale-free Networks, Complex webs in nature and technology (2007).
Strogatz, S. (2001). Exploring complex networks. *Nature, 410*(6825), 268. doi:10.1038/35065725
Watts, D. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*(6684), 440-442. doi:10.1038/30918
Watts, D. (1999). Networks, dynamics, and the Small World phenomenon. *American Journal of Sociology, 105*(2), 493-527. doi:10.1086/210318
Watts, D. (2004). The "new" science of networks. *Annual Review of Sociology, 30*, 243. doi:10.1146/annurev.soc.30.020404.104342
Yang, D. (2010). *The network lens*
Zeisel, J. (1981). *Inquiry by design : Tools for environment-behavior research* Monterey, Calif. : Brooks/Cole Pub. Co.