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Fuzzy Cognitive Maps: A Design Research Tool to Address Systems of Scaled Complexity

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Fuzzy Cognitive Maps: A Design Research Tool to Address Systems of Scaled Complexity

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of

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ABSTRACT

It is the contention of this thesis that Fuzzy Cognitive Mapping is one tool to manage the design research process under conditions of scaled complexity as design plays a larger role in the “wicked problems” of the 21st century. Fuzzy Cognitive Maps (FCMs) are an appropriate tool for design research as they are born out of the constructivist philosophy and the notion that knowledge creation is a socially rooted process of human-centered discovery in which connections are made between different ideas and areas of knowledge. The “fuzzy” component (Fuzzy Logic) of FCMs allows for better decision making when the information is not always complete and data is noisy, when thresholds are ambiguous and interactions are not accurately assessed. FCMs are graphical representations of structured knowledge, represented by concepts linked by directed, weighted, and signed (positive, negative) edges. The hope is that such a tool will be a meaningful addition to designers’ knowledge-base when applying their design abilities to solve complex, societal issues.
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I. Introduction

Background

In the last 40 years, “modern design has grown from a focus on products and services to a robust set of methods that is applicable to a wide range of societal issues” (The Design Collective, 2014). The term “design,” as used in this thesis, refers to an “applied art” concerned with the disciplines of graphic, industrial, interior, and fashion design. As an evolving discipline, this thesis explores four main stages of development of the field of design - a discipline transitioning from (1) a focus on improving the intrinsic value of goods and services through mass manufacturing techniques, (2) to a focus on enhanced appearance and aesthetic value, (3) followed by an emphasis on designing products to meet the needs and capabilities of all people, leading to what some consider a present perspective on the discipline, (4) which is a field concerned with design as a way of thinking (Buchanan, 1992).

As designers become more adept at understanding the fundamental issues motivating the needs of users, their methodologies of problem solving have been codified and perfected. Today, there is growing recognition that these methods are increasingly useful when applied to challenging, complex, and ambiguous problems afflicting our society. However, although design tools exist that begin to address these issues (personas, scenarios, journey maps, and mind maps, to name a few), this thesis proposes a novel design research method that is better suited to manage the complexity of systemic issues, while maintaining the uniqueness of concepts within the system (Pruitt and Grudin, 2003; Hanington and Martin, 2012).

Fuzzy Cognitive Maps are born out of the intersection of cognitive mapping and Fuzzy Logic. Cognitive Mapping is a methodology that stems from the philosophy of constructivism as
proposed by Dewey, specifically the philosophical epistemology of constructivism defined by Bruner (Buchanan, 1992). Bruner’s interpretation of constructivism posits that true learning occurs when one is required to draw on past experiences and existing knowledge to discover facts, relationships, and new information (Cunningham and Duffy, 1996). The second defining component of Fuzzy Cognitive Mapping, Fuzzy Logic, is a theory of computational logic (in direct contrast to binary) and is a system for computing with words rather than numbers (Zadeh, 1990). Fuzzy Logic establishes quantifiable relationships between otherwise ambiguous concepts in a way that closely follows human intuition. Fuzzy Logic, therefore, serves as a theoretical approach for building a bridge between objectivity and subjectivity.

**Purpose**

The purpose of this thesis is to propose a design research tool that enhances the systems thinking ability of designers in order to (1) understand context of complex, ambiguous problems and (2) envision possible unexpected interactions and outcomes through directed “what-if” explorations. Systems thinking is a key skillset designers need to understand the complexity of the problems they are increasingly being asked to solve. It is an approach to problem solving that attempts to balance a holistic understanding of a system with an understanding of the component parts and their relationships (Meadows, 2008). The relevance of proposing such a tool was born out of contextual investigation of the evolution of design and its education and future directions of the discipline in industry. The hope is that such a tool will be a meaningful addition to designers’ knowledge-base when applying their design abilities to solve complex, societal issues.

The research in this thesis explores the context necessary for understanding the broader applications of design as a practice for solving societal issues. It makes hints at the future trajectory of design as a discipline. And finally, this thesis presents a research tool, new to the
field of design according to my research, that is both responsive to a future trajectory and appropriate in the classroom and in industry. In order to formulate this contextual understanding, a literature review was conducted to answer:

*How has the industry of design evolved to address systems-level problems?*

*What is Fuzzy Cognitive Mapping and what are its origins?*

*In what context might Fuzzy Cognitive Mapping be useful for designers?*

**Significance**

As a society we are in the midst of a transition, hopefully to more sustainable and resilient ways of being. Unfortunately, accomplishing this shift will be no easy feat. The challenges we face are complex, ambiguous, and rapidly changing. With global population quickly reaching 10 billion, issues of health, education, transportation, and environmental degradation are ever-more complicated. Literature suggests that designers are increasingly being called upon to use their skillsets to address these issues (Rittel, 1973).

Presenting Fuzzy Cognitive Maps as a tool for designers is useful in that it addresses the need for systems thinking tools within the design curriculum given the 21st century “wicked problems” designers are facing (Buchanan, 1992). It provides one strategy for information gathering and concept development, which can be an ambiguous and unstructured task (Dorst and Dijkhuis, 1995).
Reflexive Narrative

Somewhere in the course of our lifetime, usually based on the academic areas in which we excel – science, art, math, writing – we are sorted into two groups – the “creatives” and the “practical people,” or those who are right-brain dominant and those who are left-brain dominant. I was made aware of this distinction around age 12 in my 8th grade art class.

On the first day of a semester-long course, my middle school art teacher announced that he would be informing the “creative” students of his recommendation for their participation in the Advanced Placement Art program when we matriculated to high school next year. As a new student, I didn’t appear to be one of “the creatives” based on my educational profile - I was taking advanced math classes, I was in the accelerated English program, and was enjoying my science courses.

Unfortunately, my “profile” did not provide a comprehensive overview of my personhood and therefore my teacher was unaware of my prior experience in the arts. Not only was art an integral part of my Montessori education during the previous 10 years, I enjoyed the lessons so much that I pursued group instruction outside of school where I was taught to draw, watercolor, oil paint, throw pottery, and use other forms of mixed media. Given the limited information my art teacher had about my experiences, he did not recommend me for the advanced art program and instead suggest take a foundations course if I felt so inclined.

As the semester progressed, I quietly accepted that I must not be “one of the creatives” - an art teacher would know best, after all. Nearing the end of the semester, I’d pushed the thought to the back of my brain until the day I received an impersonal note from my teacher notifying me that I would qualify for registration in the Advanced Art program. By that point, my mental
model was set and I didn’t consider myself “one of the creative students” – I thought, “I must be skilled enough to dabble in their realm, but it does not belong to me.”

Fast forward to summer before my senior year of high school when I attended a month-long Architecture intensive. The experience was extraordinary – I received an excellent overview of the field, was taught perspective drawing, completed a capstone design project, and visited architecture firms all over St. Louis. But once again, when I returned to school my senior year, I couldn’t envision how my science or math courses had any relation to the creative practice of architecture. With very little feedback about my performance in the program, I was left to consider if this intense practice was a journey I could envision myself pursuing for the next 4-plus years. Ironically hesitant about the workload required of Architecture students and unsure of my ability, I decided to “play to my strengths” (the areas in which I’d always been encouraged) and pursue a degree in biomedical engineering.

After 4 intense years of engineering education and 2 unfulfilling years in corporate, I decided to finally acknowledge my predisposition for the creative fields and apply to Master’s programs in Design. Design school developed my divergent, creative muscle and finally gave me the formal acknowledgement that I might consider myself “a creative.” Yet, still I felt unqualified to be there. I confessed to one of my advisors that I’ve felt a sense of “imposter syndrome” and questioned my legitimacy of being in Design School many times. Although a challenge, the awareness that I didn’t fit the traditional mold has been a productive and meaningful part of my experience. It has shaped the path that I carved over my two years in the Masters program and has helped me to define who I am as a Designer.

After a semester of being exposed to traditional Design methodologies – drawing, ideation sketching, prototyping, woodworking, and model-making – I realized two short years
would not make me a domain expert in any single area of design (Industrial, Fashion, Graphic, Communication). Instead of pursuing a path in which I’d be competing with students who had 5 years of intensive discipline-specific design education coupled with 2.5 years of real work experience, I challenged myself to consider how I might leverage my existing skills to make a meaningful contribution to the field. With a deep belief that all of my experiences could add up to a meaningful advantage, I decided to expand upon my analytical abilities and stretch my mind with my developing lens of creativity.

Over the next one-and-a-half years, I filled my electives with business courses in Service Design and systematic innovation, I conducted independent research in Design Ethnography, I took engineering classes in Systems Engineering, and I completed a certificate in Permaculture (a systems-thinking sustainable Design practice). My thought was, if I won’t be competitive as a specialist, I can develop my skills as an expert generalist.

As a non-traditional student, there will be traditionalists who rightfully question students from alternative backgrounds. A deep appreciation for the arts and honed craftsmanship will always be cornerstones of Design as a formal discipline. However, designers are being called upon more frequently to tackle “wicked problems” which require a different, complementary skillset (Rittel and Webber, 1973; Buchanan, 1992). Given such challenges, we must have the fortitude to acknowledge the new frontiers of Design and the wisdom to shepherd a new type of creative pragmatist into our Design schools. It was in 1965 that L. Bruce Archer, professor of Design Research at the Royal College of Art argued that design is “not merely a craft-based skill but should be considered a knowledge-based discipline in its own right, with rigorous methodology and research principles incorporated into the design process.” David Kelley of IDEO believes, “creativity is not the domain of only a chosen few” and research suggests that
creativity is in our very nature as human beings and that our creative abilities can be enhanced with encouragement and practice (Hamm and Adams, 1992).

Scope and limitations of the project/inquiry

It is important to note that this research is more exploratory and speculative than generalizable and prescriptive. The following literature review presents one argument for the evolution of design and is not intended to be comprehensive. The aim is to illustrate a singular lineage of design as it relates to design moving from a discipline concerned with signs, things, and actions to one concerned with signs, things, actions, and ideas on a systemic level. As such, this investigation borrows ideas from many disciplines based on the premise that “design problems are ‘indeterminate’ or ‘wicked’ because design has no special subject matter of its own” (Buchanan, 1992). Therefore, what some may consider a weakness of this study can in fact be considered an asset.

For those who may reject Fuzzy Cognitive Maps on the basis of relativism, it is inherently the responsibility of the designer to have a perspective on the subject and to accept full responsibility for outcomes from designed solutions - “The wicked problem solver has no right to be wrong - they are fully responsible for their actions” (Rittel and Webber, 1973, p. 16). The value of Fuzzy Cognitive Maps lies in their inclusive nature for knowledge building. However, in order to measure “true efficacy” within the design process, a study must be conducted comparing a design solution that utilized Fuzzy Cognitive Mapping during the research phase versus design solutions that did not use additional formalized research methods.
II. Review of the Literature

Introduction

The following literature review is broken into three parts: a selective history of design, the relevance of systems thinking in design, and the origins of Fuzzy Cognitive Mapping, a systems thinking tool. It is important to note, that the history presented herein details one argument for the evolution of design and is not intended to be comprehensive. The aim is to illustrate a singular lineage of design as it relates to design moving from a discipline concerned with signs, things, and actions to one concerned with signs, things, actions, and ideas on a systemic level.

A Selective History of Design

The pervasiveness of design has largely been influenced by the evolution of the manufactured goods industry. With the dawn of the Industrial Revolution, manufactured goods became a key economic driver in Europe and America. As such, businesses recognized the utility of design and began employing its techniques and practitioners as a mechanism to increase profitability. This convergence of art and industry was the impetus for formalizing methods in design. Since that time, we have seen design evolve from a field concerned with sign making, industrial products, and architecture, to one concerned with experiences and ideals. Although it is a valid argument to say that design has always be concerned with the betterment of society, it is only in more recent years that governments and businesses have recognized design as a formal method for addressing systemic social problems.

After the dawn of the Industrial Age in the late 1700s, businesses in Europe and America recognized design as a systematic method of creating products for the emerging middle class.
Businesses viewed the designer’s primary role as increasing profitability for the industry of mass manufactured goods. Henry Dreyfuss, one of the founders of the Industrial Design profession illustrates the role of the designer in the following way, “if the point of contact between the product and the people becomes a point of friction, then the Industrial Designer has failed. If, on the other hand, people are made safer, more comfortable, more eager to purchase, more efficient - or just plain happier - the designer has succeeded” (1955, p. 8). Industry in the 1800s had not yet formed such sophisticated perspectives of Industrial Designers, however, and primarily saw their work as being concerned with form-giving and finding the “appropriate beauty” in machine-made objects (Papanek, 1971, p. 12). The primary aim of design education during this time was concerned with observation and replication and less so with the creative process.

Inspired by the philosophies of architects Frank Lloyd Wright and Karl Friedrich Schinkel, German architect Peter Behrens rose to the public consciousness for his work with Allgemeine Elektricitäts-Gesellschaft AG (AEG) in 1907. Thought to be the first Industrial Designer, Behrens successfully integrated art and mass production on a large scale. Behrens emphasized total control over all aspects of the design process and produced everything from industrial buildings to small appliances. He even established the company’s corporate identity, branding, and advertising (Anderson, 2002).

Behren’s work and ideologies greatly influenced a number of gentlemen, including Walter Gropius and Ludwig Mies Van der Rohe, who founded and led The Bauhaus school in Germany from 1919 to 1933 (Newhall, 1975). The founding of this school is arguably the most significant event in the history of formalized design education. Almost every major Design School in the United States still uses the foundation design course developed by The Bauhaus (Papanek, 1971). Its curriculum unified art, craft, and technology and laid the foundation for
modern developments in art, architecture, communication design, interior design, industrial design and typography (Raizman, 2003; Meggs and Purvis, 2011). Unfortunately, the rise of the Nazi party in Germany during World War II forced the closing of the school in the 1933, dispersing Bauhaus designers all over the world.

The Bauhaus had a major impact on art and architecture trends in Western Europe, the United States, Canada and Israel in the decades following its disintegration. Mies van der Rohe re-settled in Chicago and became one of the most distinguished architects in the world. Josef Albers settled at Yale where he established the Graphic Design program (Kelly, 1989). Walter Gropius and Marcel Breuer, fellow Bauhaus designer, went on to The Harvard Graduate School of Design where they mentored the likes of Philip Johnson and I.M. Pei. Another Bauhaus scholar, László Moholy-Nagy, went on to establish the New Bauhaus in Chicago in 1937, which eventually became part of the Illinois Institute of Technology and the first institution in the United States to offer a PhD program in Design. The most significant outcome of The Bauhaus was the establishment of the first articulation of a ‘universal visual language.’ Though some consider the craftsmen approach of The Bauhaus to be outdated, the universal visual language established by the school - texture, color, form, shape and materials - can be considered the first foray into design as not only art, but also a science (Newhall, 1975; Frayling, 2007).

“Let us therefore create a new guild of craftsmen without the class distinctions that raise an arrogant barrier between craftsmen and artist! Let us desire, conceive and create the new building of the future together. It will combine architecture, sculpture and painting in a single form and will one day rise towards the heavens from the hands of a million workers as a crystalline symbol of a new and coming faith.”

- Walter Gropius. Bauhaus Manifesto 1919
Post-World War II, many designers found work enhancing the aesthetic quality of products targeted at the growing middle class. Pulling the United States out of the Great Depression of the 1930s, World War II provided enormous economic stimulation for the country. Manufacturing was at an all-time high to meet wartime demands of weapons, ammunition, uniforms, and other materials. Following the end of the war in 1945, the United States was positioned as the most powerful economy on the globe. A growing middle class, along with the increasing buying power of women as managers of the home, paved the way for aesthetic trends, ergonomics, and a rise in intentionally designed household machines and products.

As such, the competencies of designers from all disciplines were folded into core business objectives. Industrial designers were recognized for their ability to expertly craft pleasurable experience with physical objects. Communication designers worked alongside executives and marketers to craft clear and intentional messaging with packaging design and advertising. One such designer was Raymond Loewy who spanned the fields of graphic, industrial, and transportation design. For the latter half of the 20th century, Loewy worked as a window designer for department stores such as Macy’s, Wanamaker’s and Saks. He designed the logos for Shell, Exxon, Trans World Airlines, the U.S. Postal Service, and British Petroleum. He went on to do industrial design work for Sears, Electrolux, Coca-Cola, Greyhound, Lucky Stripe and many others. Loewy also did notable work in the transportation industry - designing trains, cars, culminating in design work for NASA in the 1970s. Loewy was named “The Man Who Shaped America,” “The Father of Streamlining,” and “The Father of Industrial Design,” and was the first designer to be featured on the cover of Time Magazine (Meikle, 2010; Loewy, 2002). From this point forward, design was elevated to a new level of significance within our economic system.
Aspirations to codify design surfaced in the “design methods movement” of the 1960s. Buckminster Fuller - radical technologist, architect, system theorist, author, designer, inventor and environmentalist- proclaimed the 1960s as the “design science decade.” Fuller is most known for his work regarding practical, affordable housing and transportation and is credited with popularizing the geodesic dome (Marks and Fuller, 1973). As an influential figure of the time, Fuller called upon design practitioners to root their methodologies in science, technology, and rationalism and to join a greater movement to overcome the social and environmental problems that he believed could not be solved with politics and economics alone. Herbert Simon, another influential and controversial figure in the design science movement, published his book “The Sciences of the Artificial,” which called for “a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process” that could be taught at the university level (Cross, 2001; Fuller, 1999; Simon, 1969, p. 113).

As discourse around design procedures and practices was elevated within the academic community, so too were discussions regarding the intentions of design. In 1973, Rittel and Webber published their seminal paper “Dilemmas in General Theory of Planning” which characterized design and planning problems as “wicked” problems, fundamentally in contrast to the techniques of science and engineering, which dealt with “tame” problems. They note that during the industrial age, the motivation of designers and planners was largely dominated by the idea of efficiency, but practitioners as of late had begun to focus on questions of what is fair and equitable. These designers recognized that the problems they were tasked with solving were issues of social and policy planning, marked by a plurality of objectives, stakeholders, and possible solutions. Ten years later, Victor Papanek published his book “Design for the Real World” (1983), which also critiqued the objectives of the industrial economy and the frivolous
products that are a byproduct. Papanek instead provided a framework for a more responsible approach to design for a world with diminishing resources and energy. Papanek spent much of his career encouraging designers to explore areas of application outside of the military-industrial complex.

Between 1960 and today, many sub-disciplines of design have emerged out the premise that design not only serves the function of creating aesthetically pleasing products, but can also be applied to making the artificial world more usable and accessible. In 1963, British designer Selwyn Goldsmith, published the book *Designing for the Disabled* which pioneered the concept of free access for disabled people. In 1988, Don Norman published his book “The Design of Everyday Things,” popularizing the phrase user-centered design. In 1989, After almost 20 years of practicing accessible design, R. L. Mace founded The Center for Universal Design at North Carolina State University, which sought to provide a central place for the study of buildings, products, and environments that are accessible to aging people, people without disabilities, and people with disabilities. In 1991, William Rouse published “Design for Success: A Human-Centered Approach to Designing Successful Products and Systems,” which offers a comprehensive framework for human-centered design of complex systems. And in 2015, Ezio Manzini published “Design, When Everybody Designs: An Introduction to Design for Social Innovation” in which he describes an open-source social innovation movement in which all citizens participate in the design process.

Although design found its economic footing as a result of the evolution of the manufactured goods industry, it has always been an underlying contention of designers to create a better, more usable, more accessible world. We have only recently seen government and business recognize design as a field concerned with sign making, architecture, industrial
products, and one concerned with experiences and ideas. As design as a way of solving societal challenges becomes an increasingly recognized approach, the field will benefit from tools that are aimed at solving systemic problems.

**Systems Thinking in Design**

“The ultimate goal of design is to transform man’s environment and tools and, by extension, man himself. Man has always changed himself and his surroundings, but recently science, technology, and mass production have advanced so radically that changes are more rapid, more thorough, and often less predictable. We are beginning to define and isolate problems, to determine possible goals and work meaningfully towards them... The various sciences and technologies have become woefully compartmentalized and specialized. Often, more complex problems can be attacked only by teams of specialists, speaking on their own professional jargon. Industrial designers, who are frequently members of such teams... must act as a communication bridge between other team members. Many times the designer may be the only one able to speak the various technical jargons... so we find the industrial designer becoming the team synthesis, a position which he has been elevated by the default of people from other disciplines.”

- Victor Papanek, Design for the Real World, 1971, p. 29

Victor Papanek wrote these words over 40 years ago, but now, more than ever, they hold true. By virtue of their educational background, designers “must act as a communication bridge between other team members” (Papanek 1971, p. 28). They must become experts in recognizing the insights that exist between compartmentalized and specialized knowledge and they must be
able to dream of solutions that *transcend* any one discipline. This is the role of the designer of the 21st century. As such, it is necessary for designers hone their systems thinking skills.

It is widely accepted that systems thinking is a critical tool in addressing the many environmental, social, political, and economic challenges facing humanity (Meadows, 2008; Norman, 2015; Stroh, 2015). Society is increasingly recognizing that design is an activity concerned with systems. Rittel and Weber may have been the first to define design and planning problems as “wicked” problems, however modern designers have expanded upon design as a systems-level activity: Findeli theorizes that “a new logical structure of the design process is: (1) Instead of a problem, we have: state A of a system; (2) Instead of a solution, we have: state B of the system; and (3) The designer and the user are part of the system (stakeholders)” (2001, p. 10). As such, Fuzzy Cognitive Maps are an appropriate tool for design research as they are concerned with documenting and digesting systems.

**Fuzzy Cognitive Maps**

Among their various applications, Fuzzy Cognitive Maps are used to represent mental models, or belief *systems*, and as such, are well-positioned to serve as a methodology for developing design “placements” (Gray et al., 2014). Design placements are the tools designers call upon to shape design challenges by considering the views of all participants and the context of the problem (Buchanan, 1992). A few of the instances in which Fuzzy Cognitive Maps have been applied in the context of understanding disparate points of view include documenting stakeholder perceptions of local ecosystems with regards to infrastructure planning, understanding consumer satisfaction in the banking industry, mapping the complexities of the migrant experience, and using stakeholder knowledge to achieve corporate responsibility with
regards to product planning (Nasserzadeh et al., 2008; Văidianu et al., 2013; Tezcan, 2013; Jetter and Sperry, 2013).

Fuzzy Cognitive Maps are a methodology rooted in theories of generative knowledge, well suited for developing a systems-level perspective of concepts and shared connections. The “fuzzy” (Fuzzy Logic) component of Fuzzy Cognitive Maps allows for better decision making when the information is not always complete and the data is noisy, when the thresholds are ambiguous and the interactions are not accurately assessed. These characteristics suggest that Fuzzy Cognitive Mapping is a useful tool for researching design problems of scaled complexity.

Herbert Simon, notable figure in the design science movement, was noble in his call to codify design methodologies. However, proposing design as a science, rooted in the rigorous, linear methodologies is often criticized as constraining by design practitioners (Dorst, 2006; Hatchuel, 2002). Many of the more recent design methodologies, such as co-design and participatory design, are rooted in constructivist theories of knowledge creation, as opposed to Simon’s positivist theories.

Positivism is a philosophical paradigm that is rooted in empiricism. Positivists believe that information derived from sensory experience and interpreted through reason and logic is the only form of true knowledge. Constructivists, on the other hand, believe that knowledge is socially rooted, human-centered discovery, in which connections are made between different ideas and areas of knowledge (Cakir, 2008). Constructivists also posit that knowledge construction is most effective when people are active in making tangible objects in the real world. It is not the fault of Simon, or any others, that the attempts to methodize design have been mostly positivist, however, approaching design methods from this perspective betrays the nature of design.
Although design methodologies have been largely rooted in positivist epistemologies (“design as a science”), recent trends in the field suggest the design process is undergoing a paradigm shift (Findeli, 2001). That is, design is inherently a constructivist practice as suggested by Schon (1983). Positivist doctrine states that design is a problem solving process in which the problem definition is stable and defines the solution base that needs to be surveyed.

“[A]ssumptions of positivism… are appropriate in a physical science… but may be inappropriate when approaching a complex social science phenomenon” (Sobh and Perry, 2006). The Constructivist viewpoint approaches knowledge as a system of layered perceptions. With respect to design, this means every design problem is unique, a “universe of one” (Dorst and Dijkhuis, 1995).

One theory stemming from constructivism is that of constructionism. Constructionism is a learning theory in which learners construct mental models to understand the world around them. Constructionism was defined by Seymour Papert and builds on Jean Piaget’s epistemological theory of constructivism and ideas of experiential learning (Papert, 1987). Constructionists believe that learning is socially rooted, is a process of human-centered discovery, is developed via the connections between different ideas and areas of knowledge, and most effective when people are active in making tangible objects in the real world (Alesandrini and Larson, 2002; Cakir, 2008). Cognitive maps have their roots in constructivism.

Fuzzy Cognitive Maps are an extension of Concept Maps, formalized by Joseph Novak in 1971. Cognitive Maps are graphic organizers for representing our individual constructions of the world. They are defined by webs of linked concepts that display how our minds represent contexts defined by an explicit "focus question.” Concept Maps aid creativity, reveal the interconnection between relationships, and provide an organized structure for knowledge. Fuzzy
Logic, the differentiating quality of Fuzzy Cognitive Maps, is a theory of computational logic (in contrast to binary) and is a system for computing with words rather than numbers (Zadeh, 1990). It establishes a quantifiable relationship between otherwise ambiguous concepts in a way that closely follows human intuition.

Fuzzy Cognitive Maps were first introduced by Bart Kosko in 1986. They are represented by concepts linked by directed and signed (positive, negative) edges. Fuzzy Cognitive Maps are distinct from cognitive maps in that their relationships are weighted. These causal relationships are of varying intensities and are represented by fuzzy numbers between 0 and 1 (Kosko, 1986). Fuzzy Cognitive Maps provide a better conceptual understanding of the focal problem as they provide depth by assigning significance among otherwise “fuzzy” concepts within the problem. The quantitative dimension of Fuzzy is the critical element that bridges the gap between objectivity and subjectivity and marries the positivist epistemology to the constructivist.

Fuzzy Logic allows for better decision making when data is not always neat, complete, and well understood. Or, when data can have many different meanings, depending on the stakeholder interpreting the data. As such, Fuzzy Cognitive Maps are well positioned as a methodology for developing “placements,” which are the instruments by which designers intuitively or deliberately shape design situations. These placements can be used as points of deeper exploration and concept development within the design process (Buchanan, 1992). Placements can occur at a single node within a Fuzzy Cognitive Map or might occur across the entire system of nodes represented by the map. Because of their organized and inclusive nature, Fuzzy Cognitive Maps are a useful tool for researching design problems of scaled complexity.
III. Methodology/Methods

Research/project design

The following chapter presents a proposal of how Fuzzy Cognitive Maps could be used in the design setting. Two activities were pursued in support of this proposal:

1) A single case study was conducted by applying the Fuzzy Cognitive Mapping technique to a relevant “wicked problem, namely the Flint Michigan Water Crisis.” Notable systems thinking framework “Leverage Points” (Donella Meadows) was utilized for identifying potential design placements.

2) Following the case study evaluation, a design workshop was conducted with 15 willing Masters of Design students from a School of Design located within a Midwestern, Research I institution. In this 2017 workshop, an anonymous survey was distributed to assess the perceived usefulness of Fuzzy Cognitive Mapping for designers.

Methods of inquiry/analysis

A “wicked” societal problem (the Flint Michigan Water Crisis) was selected on the basis of relevancy and significance. The crisis is relevant in that it was the subject of national news for over (1) year and significant in that 40% of its nearly 100,000 residents were impacted (Flint Water Crisis Facts). A literature review was conducted to assess the problem and gather inputs for the Fuzzy Cognitive Map. Other points of data collection that were considered for this study are discussed in the limitations section.

The data collected was then input into an open-source Fuzzy Cognitive Mapping software, Mental Modeler. Once the FCM was created, the output was analyzed for potential placements of design intervention using Donella Meadows’ well-cited systems-thinking
framework, “Leverage Points” (See Table 1. below). A series of “what-if” questions was then asked at each identified Leverage Point as proposals of possible design interventions. Based on the “Leverage Points” assessment, questions were extrapolated and generalized for the creation of a question bank that could be used for future investigations of wicked problems.

The map below (Figure 1.) was created using Mental Modeler and then refined in Figure 2. for clarity.

![Flint Michigan Water Crisis Mental Modeler FCM](mentalmodeler.org)
As mentioned, a series of “what-if” questions are proposed in Table 1. to illustrate placements of potential design intervention if this Fuzzy Cognitive Map were to be carried forward into a proposed design solution. The intent of this activity is to illuminate the numerous interactions and placements that a Fuzzy Cognitive Map can bring attention to.
Methods of data collection

The activities in the following section were conducted in an effort to assess the perceptions of Fuzzy Cognitive Maps and their potential usefulness among Designers. A pilot workshop was conducted with fifteen (15) first year Master of Design students. Students were asked to download Mental Modeler (mentalmodeler.org), an online, open source Fuzzy Cognitive Mapping tool prior to the workshop. Students were directed to a brief tutorial explaining what Fuzzy Cognitive Maps are and how to use the FCM software. Six (6) potential
focal questions were developed prior to the workshop based on the topics of investigation of the course. The questions included:

1. How will open source data and a local definition of “healthy” impact how consumers invest in their health and fitness in 10 years?
2. How will open source data and a universal definition of “healthy” impact how consumers invest in their health and fitness in 10 years?
3. How will urbanization and innovation in physical infrastructure impact how consumers invest in their health and fitness in 10 years?
4. How will urbanization and open source data impact how consumers invest in their health and fitness in 10 years?
5. How will open source data and innovation in physical infrastructure impact how consumers invest in their health and fitness in 10 years?
6. How will urbanization and a local definition of “healthy” impact how consumers invest in their health and fitness in 10 years?

At the beginning of the workshop, students selected which of the six focal questions they would like to collectively investigate. They chose to investigate questions five (5), “how will open source data and a local definition of ‘healthy’ impact how consumers invest in their health and fitness in 10 years?” Students were given 30 minutes to work individually on a Fuzzy Cognitive Map addressing the focal question. Students were then asked to work in groups of 3 for 30 minutes to combine their Fuzzy Cognitive Maps. Upon completing their Fuzzy Cognitive Maps, students were given an anonymous survey assessing the value of the FCM to their Design work (See Table 2. below).
# Data sample

When asked “What is the likelihood that you would create a cognitive map to better understand a complex problem in the future,” 73% of respondents were ‘very likely’ (score of 7-10) to create a cognitive map again in the future. 27% of respondents were ‘neutral’ or ‘unlikely’ (scores in the range of 1-6) to create a cognitive map in the future. When asked “How likely are you to recommend cognitive mapping to a friend,” 60% of respondents were ‘very likely’ (score of 7-10) and 40% of respondents were ‘neutral’ or ‘unlikely’ (scores in the range of 1-6) to recommend Fuzzy Cognitive Mapping. Based on these statistics, a Net Promoter Score of 20% was calculated, which is a metric used in industry to gauge a user’s overall satisfaction with a product or service.

<table>
<thead>
<tr>
<th>#</th>
<th>How did your group make decisions about which CONCEPTS/COMPONENTS to include from the individual maps into the group map?</th>
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<th>When deciding which CONCEPTS/COMPONENTS to include in the group cognitive map, how did you move forward with a decision?</th>
<th>What is the likelihood that you would create a COGNITIVE MAP to better understand a complex problem in the future (1 - 10)?</th>
<th>How likely are you to recommend COGNITIVE MAPPING to a friend (1 - 10)?</th>
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<tbody>
<tr>
<td>16c03a7f4e7b2443c60447507409cfe</td>
<td>We found common threads and discussed about it</td>
<td>The differences in structure and definition</td>
<td>we discussed and voted</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>b2c118ebdac3b6db86d1b0196c07e5bb</td>
<td>We tried to find common themes and discussed about what to include</td>
<td>It was not easy, because we had done very different things. Our way of thinking is different, so trying to find a common structure was complicated.</td>
<td>We tried to agree on all of them, and sometimes concede even if it was not our idea.</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>15e841e7be8be04fd3d93d3a04da7f</td>
<td>We collected all the input and rephrased some of them</td>
<td>Its getting more and more complicated</td>
<td>We discussed with each other to listen to the original POV and then proceed selectively</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>d258f116f0269e57</td>
<td>we spoke together and finding the right</td>
<td></td>
<td>We discussed as a group</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ID</td>
<td>Description</td>
<td>Action</td>
<td>Notes</td>
<td>Page</td>
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<tr>
<td>----------</td>
<td>------------------------------------------------------------------------------</td>
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<td>------</td>
<td></td>
</tr>
<tr>
<td>75684a706390efb0</td>
<td>decided which one to include words and we all agreed if it worked</td>
<td></td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>cf3e5e443cb76c9ed364a94390a57300</td>
<td>Discussion Simplify and filter some factors. Thinking about the related components.</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>c4423dd9ea55fad741cb6edc108892e</td>
<td>Trying to find common themes. We started from different perspectives. We discussed and voted for each one</td>
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<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>564450587bbdaed6198551d44f2f6ec4af</td>
<td>We discussed the concept and came to an agreement. Defining more concrete concepts Trying to find a relationship with another concept right away.</td>
<td>9</td>
<td>6</td>
<td>9</td>
<td></td>
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<tr>
<td>88a449ec15c75f2e03adf35f8bc3ba3</td>
<td>We included everyone's input and connected the concepts. We had overlapping concepts which helped combining. But we more or less just kept what everyone had on our individual maps. We used most of everyone's concepts.</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>09c0489a7885184aad6e91fe8f8a170e8</td>
<td>Level of importance / Positive and Negative impact I thought it was easier to combine ideas, so the group activity was easier Previous information about the field + Related subjects.</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td></td>
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<tr>
<td>2b56b8b05bf1ad5395131b490bd0c2</td>
<td>we broke up broad concepts in two in order to make them more specific some concepts were too broad and they didn't work together well taking the most articulate and clear.</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2545ec035285a50d3107681a401696</td>
<td>Luckily we each had captured different parts of the system on our individual maps. Coming together we started with what we felt were most important. Individually we likely focused on parts of the system we were most interested in. It was perhaps hardest to take emphasis away from our individual passion points. Make a good pitch for an idea and be flexible.</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1236eff6f0f56ed817811d6a29b2201</td>
<td>First put the main point form personal to the map, and then find connection between them. Last discuss about the weight of the relationship. As I can't put all the personal map into group map, so it's hard to split the personal map and drag some single thing out of the net. I decided it by looking at how much relationship it has with other elements. The more the important.</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>6d8084ef7b5fa7ef95311df2f56730d</td>
<td>Starting from a basic framework that included the primary topics chosen individually, we included our basic concepts, connected them and then expanded upon them as a team. I found our process of integration (combining) was easy as we all shared similar insights and were able to integrate them without any major new cognitive Once we agreed to the concept/keyword, we then discussed the arrow directionality and weight and then proceeded onwards towards additional concepts/keywords if a connection arose or we</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
shifts. simply moved on to additional separate topics.

we discussed and synthesize the data of each one. then came out with a reasonable and logical outcome.

well,...people always have different opinions. maybe the definition of each word is different from one to other. at this point we will debate to each other.

JUST think deeper, and dig out more potential aspects that may emerge.

Try to find some similar section, and get them together.

Most of our ideas are different from each other, so I think it's easy to combine them.

Firstly combine similar words, then get them into a group, try to find the connection between each word.

Table 2. Unstructured data responses to “Perception of FCM” Survey
IV. Discussion

Based on the literature review, a case study, and anonymous survey of Masters of Design students, Fuzzy Cognitive Mapping is a useful and relevant tool for digesting the complexity of ambiguous, multi-dimensional problems. The selective history covered in this literature review reveals that although design found its economic footing as a result of the evolution of the manufactured goods industry, it has always been an underlying contention of designers to create a better, more usable, more accessible world. We have more recently seen government and business shift their understanding of design from a field concerned with sign making, architecture and industrial products, to one concerned with methods of problem solving. As such, the field will benefit from tools that are aimed at solving systemic challenges of scaled complexity.

Fuzzy Cognitive Maps are well positioned as a methodology for identifying places of potential design intervention as they allow for better problem analysis and decision making under conditions of uncertainty. Fuzzy Cognitive Maps are a methodology rooted in theories of generative knowledge, well suited for developing a systems-level perspective of concepts and shared connections. These characteristics suggest that Fuzzy Cognitive Mapping is a useful tool for researching design problems of scaled complexity.

The case study and student workshop also support the proposal that Fuzzy Cognitive Maps hold promise for handling complex, ambiguous multi-variate problems. It may be worth mentioning that inputs to the case study were collected via a literature review, however other methods of data collection for future investigations include in-depth unstructured interviews (stakeholder and expert), participant observation, action research, and grounded theory research. These methods were excluded as the main goal of this study was to assess the usefulness of the
tool and not to assess the accuracy of the inputs. These methods were also excluded for the sake of time.

Surveys administered post-workshop prove that future designers are not only willing to use this tool; they view it as a useful addition to their toolbox. 73% of participants in the workshop stated they were ‘very likely’ to use Fuzzy Cognitive Mapping again in the future and 60% of respondents were ‘very likely’ to recommend Fuzzy Cognitive Mapping to a friend. However, in order to measure “true efficacy” of utilizing Fuzzy Cognitive Mapping during the design process, a study must be conducted comparing a design solution that utilized FCMs during the research phase versus design solutions that did not use formal research methods.
V. Conclusions, Implications, Future Directions

Designers are already adept at managing complexity and the “fuzzy front-end” of design. However, Fuzzy Cognitive Maps are one proposal for a transdisciplinary research tool to manage the scaled complexity of the problems that designers are facing in the 21st century. The directed review of design history, the development of design methodologies, and some of the more recent sub-disciplines of design within this thesis support the notion that design is a method of problem solving not only concerned with signs, things, actions, but also with ideas and ways of thinking.

The Flint Michigan water crisis case study illustrated that Fuzzy Cognitive Maps are an appropriate tool for handling complex, ambiguous multi-variate problems. The design workshop proved that future designers are willing to use Fuzzy Cognitive Mapping and see it as a useful tool, evidenced by feedback gathered from the participants. Fuzzy Cognitive Mapping is not only an appropriate tool in theory, it works when applied to real problems.

This tool might be enhanced further by creating an intelligent algorithm that could autonomously conduct the questioning-asking process, thus saving designers time and money as well as being able to draw on a wealth of knowledge accumulated by analyzing many past design failures. In order to do so, Fuzzy Cognitive Mapping would need to be utilized to assess hundreds of notable design failures in order to develop a bank of generic questions. An intelligent algorithm might then sort through the question bank and apply the relevant generic questions to future design problems. At this point, data-mining capabilities could be incorporated such that the algorithm can search the web to answer the generic questions applied to the design problem and identify possible points of failure. Ultimately, the software could be utilized to analyze the risks associated with each and every proposed design intervention and suggest a preferred courses of action with the interest and health of the citizens as the top priority. The
software has the ultimate ability to promote collaborative, inclusive, transdisciplinary approaches to problem solving.

As alluded to in the personal narrative, students are not always encouraged to define themselves by skillsets that typically fall outside of their native disciplines. As such, designers are typically known for their creativity, their craftsmanship, or their aesthetic eye. Scientists and engineers are typically thought of as the problem-solvers and analytical thinkers. However, systems thinking is a skillset necessary for all globally-minded citizens - whether they fall towards the creative end of the spectrum, or towards the analytical end. Given the current practices in design education and design methodologies, Fuzzy Cognitive Mapping is an appropriate transdisciplinary tool to bridge the gap between “creatives” and “practicals” and encourage students and future designers to realize that we are all hybrids.
VI. References


Flint Water Crisis Fast Facts. Retrieved from


VII. Appendix

Figures

Figure 1. Flint Michigan Water Crisis Mental Modeler FCM (mentalmmodeler.org)
Figure 2. Flint Michigan Water Crisis Refined FCM
### Tables

<table>
<thead>
<tr>
<th>LEVERAGE POINT</th>
<th>POTENTIAL POINT OF DESIGN INTERVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Delay</td>
<td>What if there were sensors placed on screens running through the water distribution pipes that detected contaminants in real-time?</td>
</tr>
<tr>
<td>Numbers</td>
<td>What if there were sensors placed on screens running through the water distribution pipes that detected contaminants exceeding acceptable levels?</td>
</tr>
<tr>
<td>Buffers</td>
<td>What if the city of Flint contracted water from multiple sources?</td>
</tr>
<tr>
<td>Stock-and-flow Structures</td>
<td>What if critical nodes were identified as a place of design intervention and data collection?</td>
</tr>
<tr>
<td>Balancing Feedback Loops</td>
<td>What if real-time data regarding water contaminant levels was open-access on county websites, preventing Mayor Walling from suppressing residents’ concerns (balancing feedback loop) by assuring the water is safe and pure, while having no data to back up these claims?</td>
</tr>
<tr>
<td>Reinforcing Feedback Loops</td>
<td>What if there were sensors placed on screens running through the water distribution pipes that detected the contaminants resulting from the interaction between the corrosiveness of the water and the lead pipes leading to more and more lead leaching into the drinking supply over time?</td>
</tr>
<tr>
<td>Information Flows</td>
<td>What if there were sensors placed on screens running through the water distribution pipes that detected contaminants exceeding acceptable levels?</td>
</tr>
<tr>
<td>Rules</td>
<td>What if city officials received more direct forms of punishment (fines, removal from office) if city fails to notify EPA?</td>
</tr>
<tr>
<td>Self-organization</td>
<td>What if independent professional agencies were in place to monitors critical systems in our society for the benefit of the citizen?</td>
</tr>
<tr>
<td>Goals</td>
<td>What if goals of the system were developed along will measurable performance indicators prior to intervening with an existing system?</td>
</tr>
<tr>
<td>Paradigms</td>
<td>N/A</td>
</tr>
<tr>
<td>Transcending Paradigms</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Table 1.** Systems analysis utilizing Donella Meadows’ Leverage Points
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<tr>
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<td>1fc03a7f4e7b2443e60447507409cfeaf2cd18edac3b6db86d1b0196c07c5bb151e841e7be8be04fd3d93d3a04da7fb</td>
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<td>we discussed and voted It was not easy, because we had done very different things. Our way of thinking is different, so trying to find a common structure was complicated. Its getting more and more complicated finding the right words We discussed with each other to listen to the original POV and then proceed selectively Simplify and filter some factors. We started from different perspectives. We discussed and voted for each one Defining more concrete concepts Trying to find a relationship with another concept right away.</td>
<td>8 7 7 2 2 8 8 9 9 2</td>
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<td>cf3e5e443cb76c9ed36494390a57300c4423dd9ea55fa7d141cb6edcc108892e</td>
<td>Discussion Trying to find common themes.</td>
<td>Simplify and filter some factors. We started from different perspectives.</td>
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<tr>
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<td>Level of importance / Positive and Negative impact</td>
<td>I thought it was easier to combine ideas, so the group activity was easier Previous information about the field + Related subjects.</td>
<td>2 5</td>
<td></td>
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</table>
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Individually we likely focused on parts of the system we were most interested in. It was perhaps hardest to take emphasis away from our individual passion points.

Luckily we each had captured different parts of the system on our individual maps. Coming together we started with what we felt were most important.

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I decided it by looking at how much relationship it has with other elements. The more the important.

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Once we agreed to the concept/keyword, we then discussed the arrow directionality and weight and then proceeded onwards towards additional concepts/keywords if a connection arose or we simply moved on to additional separate topics.

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<th>10</th>
</tr>
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<tbody>
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</tr>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Focal Questions Proposed for Fuzzy Cognitive Mapping Workshop

1. How will open source data and a local definition of “healthy” impact how consumers invest in their health and fitness in 10 years?

2. How will open source data and a universal definition of “healthy” impact how consumers invest in their health and fitness in 10 years?

3. How will urbanization and innovation in physical infrastructure impact how consumers invest in their health and fitness in 10 years?

4. How will urbanization and open source data impact how consumers invest in their health and fitness in 10 years?

5. How will open source data and innovation in physical infrastructure impact how consumers invest in their health and fitness in 10 years?

6. How will urbanization and a local definition of “healthy” impact how consumers invest in their health and fitness in 10 years?