DEVELOPING A COMPUTATIONAL PLATFORM FOR PARTICIPATORY RESILIENT URBAN LANDSCAPE DESIGN

A Thesis in
Landscape Architecture

by
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Abstract

The increasing attention to designing resilient landscapes in the landscape architecture discipline is a timely response to today's fast changing world. Resiliency, though, is a character of complex adaptive systems and resilient design should incorporate complexity thinking to provide sound and effective solutions. Studying complex urban landscapes requires understanding the aggregated interactions of many factors/agents in small/micro scales that shape a bigger picture in large/macro scale, a bottom-up process that acknowledges the role of citizens in shaping urban landscapes and applies a rule-based approach to ecological design. At the same time, landscape architecture as a profession lacks framework and tools to incorporate this way of thinking into the design process. In today's ever-increasing reliance of design fields on digital design tools, the available CAD tools and the way the discipline uses them, do not reflect the participatory, dynamic process of shaping urban landscapes.

This research aims to provide a framework for participatory resilient landscape design, which combine benefits of computational rule-based design, social networks and collective intelligence systems into a platform for co-designing landscapes as coupled human-nature systems. The focus of this co-design tool is on urban planting design with the concentration on small-scale landscapes such as rain gardens and edible landscapes. Although, these small-scale landscapes have tremendous potentials for combating climate change, the high cost of accessing experts' knowledge, tools and materials and lack of motivation prevent many citizens to utilize these potentials.

My research proposes first, a conceptual map/framework of participatory resilient urban planting for a generic scenario. Second, it prototypes an app that provides lay users a platform to: 1) find potential sites, 2) design and evaluate landscapes and 3) share their knowledge, experiences and materials. The app evaluates citizen-designed planting schemes based on ecological resiliency rules and shows different scenarios under extreme environmental events. Through informing users by means of visualized data related to their resources and performance and social mechanisms such as peer pressure built into the platform, the app facilitates citizen engagement in the design process for reaching neighborhood resiliency goal.
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Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Method and Process

Chapter 4: Discussion

Chapter 5: Conclusion
Chapter 1: Introduction

Introduction

Resilience is defined as the ability of a system to absorb changes, self-organize and increase its capacity for learning and adaptation (Cumming 2011, Field et al. 2012). The increased attention to designing resilient urban spaces in environmental design disciplines is a timely response to today's fast changing world (Wallace and Wallace, 2008; Wu and Wu, 2013). It is believed that the shocks that today's cities may face are different from those in the past in terms of their scale and pace due to globalization and climate change. Rapid depletion of natural resources and the increasing frequency of ecological events have been mentioned as factors that make resilience a timely focus (Eraydin & Taşan-Kok, 2013).

Resilience is a characteristic of complex adaptive systems and in order to achieve resilient landscape design solutions, landscape architects need to see urban landscape systems through the lens of complexity theory. However, incorporating the dynamic nature of complex systems in small-scale design requires acknowledging and directing the bottom-up social and ecological processes that shape urban landscapes at multiple scales (Cumming 2011).

In terms of the ecological process, although there have been several studies on landscape resilience, the link between landscape planning research at the systems scale and design decisions at smaller scales is largely missing. Moreover, designing resilient landscapes requires our attention to multiple scales. This is mainly because landscape refers to a system and in order to understand and assess its resiliency, we need to understand its different components, relationships, processes and feedbacks in nested scales. Many of the research studies on landscape resilience only focus on the large scales (like zoning and regional ecosystems - which is definitely necessary) and rarely address local interactions (Cumming 2011). At the same time, many landscape architecture projects occur at a smaller-scale, and leading practitioners in different levels of the landscape industry have become interested in incorporating the idea of resilience into their design process (ASLA, 2014).
Landscape design approaches in small-scale landscapes are largely focused on more static representations of design decisions, even when we consider factors that are more dynamic such as resiliency. This is mainly because design is considered as the embodiment of the ideas and analyses in a fixed form, while the reality of landscape is dynamic and evolving (Walliss et al. 2014). Another factor that contributes to the relative absence of consideration of the dynamic nature of landscape in the design process is the way that the discipline uses CAD (Computer-Aided Design). In landscape architecture, CAD, is mainly used for fixed representation of dynamic ideas and design. However, rule-based approaches and tools such as parametric design can be used to address this problem. A rule-based approach can bridge ecological resiliency strategies to local urban landscape design decisions through translating the resiliency strategies to quantified site scale design rules.

Landscapes are coupled human-nature systems and it is not possible to design resilient landscapes with a mere focus on ecological processes. In terms of the social processes, we need a social infrastructure that shapes resilient urban landscapes and is resilient in case of abrupt changes. In order to engage with these social processes to direct the urban systems to a more resilient level, we can utilize socio-computational systems such as collective intelligence systems and design a series of social mechanisms to provide a platform for idea flow and behavior change. The platform would help to shape more resilient communities in a social sense and help communities to move towards collective ecologically resilient urban landscape goals. This study aims to explore approaches and tools that can help landscape architects and citizens to engage with the social and ecological processes in the design of resilient landscapes.

Research Questions and Objectives

My research situates itself in the context of challenges faced in shaping resilient built environments with reference to climate change and the potential that computational systems provide for design, ecological analysis and social participation. In the context of the ever-increasing reliance of the design field on digital tools for analysis and design, this thesis aims to examine some less-explored computational approaches and tools for designing resilient landscapes with the focus on bottom-up social and ecological processes. Therefore, the primary research question is:
What approaches and tools are helpful to design resilient urban landscapes at the site scale?

This study argues that an online collaboration tool for urban design that provides both an expert system and a platform for harnessing the indigenous local knowledge of people can result in directing our urban systems to a more resilient state.

In this regard, this research proposes “making as a method of inquiry in order to address wicked problems” (Zimmerman et al., 2007, p. 496). Here, the wicked problem is how to facilitate collective efforts for increasing resilience of our urban landscapes; while the creation of the artifact (co-design tool) represents the “making” component of the method. In addressing the problem, first, I have identified the potential of using computational theories and tools (such as collective intelligence systems) for catalyzing sustainable behavior in communities to achieve resiliency goals in multiple scales. I have examined how we can design an expert system that provides users with sound strategies and ideas for designing ecologically resilient urban landscapes. Second, through the process of ideation, iterating, and critiquing potential solutions, I have prototyped an online co-design tool as a research artifact that embodies the identified theoretical and technical potentials (Zimmerman et al., 2007).

The focus of this co-design tool is on urban planting design at the scale of small landscapes such as rain gardens and permaculture gardens. This focus is chosen mainly because small-scale landscapes have tremendous potential for increasing the resiliency of urban systems under climate change scenarios through their important role in water management and food production (Okvat et al. 2011). These potentials remain under or un-utilized due to the high cost of accessing experts’ knowledge, tools, and materials, and lack of motivation among many citizens that is at least partially based on the perceived lack of knowledge to tackle such issues. The co-design tool provides designers, citizens and organizations a platform to: 1) find potential sites, 2) design and evaluate landscapes and 3) share their knowledge, experiences and even materials/tools needed for their projects. The prototype app evaluates citizen-designed planting schemes based on ecological resiliency rules and shows different scenarios under extreme environmental events. Through informing users by means of visualized data related to their resources and performance and social mechanisms such as peer pressure, the tool aims to
catalyze behavioral change and citizen engagement in the design process for reaching collective urban resilience objectives.

Significance

This study provides a novel approach for resilient landscape design. The main four contributions of this research include:

1) Providing an example of linking complexity thinking to the design process in landscape architecture
2) Acknowledging the dynamic nature of landscape design by creating a prototype platform that considers and engages with both dynamic ecological and social processes that are essential to shaping resilient landscape design.
3) Adapting collective intelligence systems approaches for the landscape design process
4) Providing an example of a rule-based expert system for ecological design that links resilience strategies to design decisions in small-scale landscape design.

Organization of this document

This document is organized into five chapters. This chapter provides an introduction to the problem and the provides the context in which the research is situated, including its significance. Chapter 2: Literature Review explores the related theories and approaches that are helpful for the design of resilient landscapes at site scale. Chapter 3: Method and Process explains the general research approach and explains the methods that have been used in developing an online platform for participatory resilient landscape design. Chapter 4: Discussion provides detailed explanation of the app's components and structure and explores different scenarios of use. Chapter 5: Conclusion provides a brief summary of the research and introduces the main future steps for continuing this research.
Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Method and Process

Chapter 4: Discussion

Chapter 5: Conclusion
Chapter 2: Literature Review

Introduction

The primary research question for this thesis is what approaches and tools are helpful to design resilient urban landscapes at a site scale? In order to narrow the context of this research area, the thesis focuses on urban planting as one aspect of urban landscape design. In addressing the research question, this thesis first introduces the concept of complexity theory, second, it explores the concept of resilience in the literature and third, it introduces less-explored computational approaches and tools that can help designers and citizens to collectively shape resilient urban planting at small scales. The chapter concludes with a summary of the major points raised by the literature review.

Complexity Theory

Before delving into the body of the literature review, it is necessary to explain systems theory or specifically complexity theory since it is an underlying theory used in developing the concept of resilience.

Systems theory was established by Ludwig Von Bertalanffy who published a book with the same title in 1968. He defines systems as “a complex of elements standing in interaction” (Von Bertalanffy 2003, p. 33). He believes that despite the different components/elements and forces in various systems such as biological, social or physical, there are similar principles applying to systems in general that are transferable between the different systems.

Different disciplines such as physics, genetic biology, and computer science contributed to the development of complexity theory which partially originated from systems theory (An 2012). Systems with complex behavior are the subject of complexity theory studies. Such behavior includes non-linearities, feedbacks, the existence of thresholds, the potential for alternative stable states, and self-organization. Complex systems with higher capacity of responding to their
environment through self-organization, learning, and reasoning are called Complex Adaptive Systems. (Cumming 2011, p11)

Complexity theory has been very influential in changing the way we understand cities. Older systems approaches see urban systems as top-down organizations while complexity theory treat them as evolving bottom up organizations (Batty 2012). The theory caused a move towards “individualistic, bottom-up explanations of urban form and behavior which links to what we know about complex systems” (Crooks 2014, p. 362). Complexity of cities can be identified at two levels: on a micro level that emerges from interactions of many parts and at the macro level which stems from the geographical, economic and social relations between cities (Beirão 2012). This understanding of cities is in coordination with recent decades’ concept of urban planning and design as a participatory process involving many factors and stakeholders.

Landscapes are also complex social-ecological systems. Urban landscapes are dynamic, ever-changing systems resulting from the interaction of many factors. Seeing ecological and social aspects of urban landscapes through the lens of complexity theory can improve the ability of landscape architects to acknowledge this dynamicity and different factors that influence and change landscape and thus, their design solutions.

Urban Landscape Resilience and Complex Adaptive Systems

Resiliency is a term that was introduced by Holling (1973) in the context of ecological science. In his article “Resilience and stability of ecological systems”, he emphasizes the importance of focusing on change rather than constancy and qualitative features rather than quantitative ones in studying systems and in particular, ecological systems. Since then the term has been expanded in terms of both its concept and application in many studies that address social-ecological systems.

Since different disciplines have touched on the idea of resilience in their specific contexts, there are many different definitions of the concept. Cumming (2011) provides two definitions of resilience. The first one is closely related to the definition of complex adaptive systems and it defines resilience as the ability of a system to absorb changes, self-organize and increase its capacity for learning and adaptation. The second definition is based on systems identity. Here,
resilience is defined “by quantifying identity and assessing the potential for changes in identity” (Cumming 2011, p13).

The concept of resilience has received much attention in urban planning and design in recent years. This attention specifically revolves around cities (Wallace and Wallace, 2008; Wu and Wu, 2013). It is believed that the shocks that today’s cities may face are different from those in the past in terms of their scale and pace due to globalization and climate change. Rapid depletion of natural resources and the increasing frequency of ecological events have been mentioned among the factors that make resilience a timely focus (Eraydin & Taşan-Kok 2013).

Different international organizations also frequently use resilience as an approach for preventing disastrous situations. The intergovernmental Panel on Climate Change (IPCC) defines resilience “as the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions” (Field et al. 2012, p 34). The World Bank Group (2013) also emphasizes the critical linkages between building climate resilience and the goal to end extreme poverty and build shared prosperity. The report argues that climate resilience should be at center of any development agenda.

In this context, landscape as an underlying social-ecological system, has received much attention. For instance, UNDP1 (United Nation Development Program) defines Landscape Community Resilience as one of the strategic themes for solving environmental and energy-related issues. The related initiatives intend to integrate ecosystem functioning and enhancing community well-being in low carbon development that maximizes resilience to climate change. In doing so, there is an immense emphasis on enhancing social capital and promoting collective actions at the local level as a sustainable long-term tool to reach resilience in any level. However, these social aspects of landscape resilience are less-explored.

Originating from ecological roots, resilience as a concept has drawn the attention of social scientists in later years (Folke 2006). While in many cases the concept of resilience has been

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studied separately in ecological and social sciences, in order to design resilient landscapes, we need an integrated approach that studies landscapes as coupled human-natural systems (CHNS). Cumming (2011) argues that the framework for integrating the studies on social and ecological aspects of resilient systems is complexity theory. Complexity theory acknowledges the dynamicity of landscapes and provide a new perspective in understanding of landscape systems, which is crucial for resiliency analysis and subsequently resilient design. Resiliency is a character of complex adaptive systems and in order to achieve resilient solutions complexity thinking should be incorporated into urban landscape design process. Studying complex urban systems requires understanding the aggregated interactions of many factors/agents in small/micro scales that shape a bigger picture in large/macro scales (Batty 2007, Cumming 2011). In order to incorporate this bottom-up thinking both in ecological and social aspects of landscape design, we need to acknowledge the role of citizens in design and adopt a rule-based approach to ecological design.

**Approaches and Tools for Resilient Landscape Architecture**

Although there have been several studies on landscape resilience, the link between landscape planning research at the systems scale to design decisions at smaller scales is largely missing. In order to see different components, relationships, processes and feedbacks necessary for assessing resiliency of a landscape system, landscape architects should pay attention to the different nested scales. Many of the research studies on landscape resilience, though, only reflect upon the large scales (which is definitely necessary) and rarely address the local interactions (Cumming 2011). This occurs while many landscape architecture projects happen at small-scale and practitioners in different levels of construction industry become more and more interested in incorporating the idea of resilience into their design (ASLA, 2014).

Incorporating dynamicity of complex systems in small-scale designs requires acknowledging the bottom-up social and ecological processes that shape urban landscapes. In the context of the ever-increasing reliance of the field on digital tools for analysis and design, this thesis aims to examine some less-explored computational approaches and tools for designing resilient landscapes with the focus on bottom-up social and ecological processes. This
chapter briefly reviews the approaches and tools that can help landscape architects to deliberately use and direct these processes in shaping more resilient landscapes.

**Social Processes** (why designing resilient urban spaces is/should be a collective task?)

This thesis argues that building resilient urban landscapes requires seeing urban design as an idea of *collective problem solving* (Batty 2013, Simon 1996). This relationship can be traced in many vernacular resilient urban systems in which citizens responded to social and environmental changes when and where they happened and could adapt themselves to the new conditions. However, modern changes in city design and management and the increasing complexity of our built environment have disrupted these bottom-up processes. Meanwhile, we have developed powerful approaches and tools such as *participatory planning and design*, *collective intelligence systems* and *online social networks*. *Participatory planning and design* has been practiced long before the advent of personal computers and goes beyond the use of computational platforms for operating a collective task. However, *collective intelligence systems* and *social networks* turned to powerful tools through the potentials of online collaboration. Despite their potential, they have not been used by landscape architects for achieving bottom up resilient landscape design. The following section provides a brief review on different approaches and their related tools.

**Participatory Urban Planning and Design**

The principle underlying the emergence of community participation in design and planning is that “the environment works better if citizens are active and involved in its creation and management instead of being treated as passive consumers“ (Sanoff 2011, p.12). Based on this rationale, the community design movement has tried to involve people in shaping and managing their environment over the recent decades (Sanoff 2011). The benefits of participatory design that have been indicated in the literature include ensuring wide acceptance of plans, developing local, deliberate democratic process in shaping built environment and bringing non-expert knowledge to the planning processes (Brabham 2010).

Different techniques have been developed for facilitating community participation and bringing people's knowledge to the planning process. “Community surveys, review boards,
advisory boards, task forces, neighborhood and community meetings, public hearings, public information programs, and interactive cable TV, have all been used with varying degrees of success, depending on the effectiveness of the participation plan” (Sanoff 2011, p.17).

These traditional techniques of participatory design and planning have several limitations. the structure of many of these meetings does not allow ample time for discussion and in many cases the most aggressive personalities can dominate the discussion (Creighton 1994, Sanoff 2011). In addition, despite the theoretical emphasis on maximizing and diversifying stakeholders, in practice, there are challenges to schedule and run inclusive public meetings (Brabham 2010). Other challenges for participatory design include marginalizing population, geographic size and diversity of the participants².

Digital participatory design and planning platforms have been used to address some of the limitations of the traditional techniques of public participation. These platforms through the use of Information and Communications Technology (ICT) (Figure 1), allow for asynchronous participation which provides ample opportunities for different people to participate based on their preferred time. They also help to extend the participation across geographical scales and social categories since all users can be given equal access to the digital platform.

Most examples of evolving links between design and planning and ICT, which is also true in realm of landscape architecture concern Geographic Information Systems (GIS) and Planning Support Systems (PSS) (Saad-Sulonen et al. 2010). PSS can be defined as “geo-information technology-based instruments that are dedicated to supporting those involved in planning in the performance of their specific planning tasks” (Geertman et al. 2015, p.3). There are several examples of PSS including geographically oriented websites with interactive land-use maps that shows building regulations or more analytical oriented PSS such as What If, CommunityViz and

² One of the other challenging aspects of participatory design process is the role of designers/professionals. Professionals as facilitators have been widely proposed in participatory design literature. Sanoff (2006, p.no page number) defines facilitation as a” means of bringing people together to determine what they wish to do and helping them find ways in deciding how to do it”. Meanwhile, many designers are afraid of their role to be reduced to facilitation whereby they could not have a chance to engage in the creative activities which is intrinsic to the design process. This traditional view of design as an individual, top-down self-centered creative activity has been challenged in recent decades. Halprin, for instance, used community participation widely as a way to boost creativity in his design (Hester 2012).
UrbanSim which are designed for planners to “consider alternative possible future spatial scenarios” (Geertman et al. 2015, p 3).

Although PSSs are dedicated to “those involved in planning” and have been used for facilitating citizen participation, in many cases they still remain expert-based systems (Saad-Sulonen et al. 2010). Other approaches such as urban computing and urban informatics that originated in “information systems and interaction design explore more mundane tools such as mobile phones and Web 2.0 systems, and their availability for use and adaptation in the urban context” (Saad-Sulonen et al., 2010, no page number). In comparison to PSS, these approaches provide a greater accessibility, usability and learnability in the context of lay-users. In addition, in many cases the PSS are focused on scales larger than site scale. In this regard approaches such as Community informatics (CI) are more relevant to our goal of participatory resilient design at small scales. CI has emerged at the intersection of aforementioned information systems and interaction design approaches with community development. It is defined as the “convergence of community with information sciences and technologies” and be seen as an area of activism for community empowerment. (Carroll 2015, Saad-Sulonen et al. 2010).

![Figure 1: ICT-mediated citizen participation in urban issues comprises aspects of the relationship between participation and technology being addressed in such areas as governance, urban planning, information systems and interaction design, geography, citizen activism and community development. Source: (Saad-Sulonen et al., 2010, no page number)
As an example of CI-assisted participatory planning and design, we can point out Urban Meditator software (Saad-Sulonen 2007), Future State College (Carroll et al. 2014) and Community Animator (Carroll et al. 2015). Although the apps provide great opportunities for initiating and collaborating on urban projects, they have shortcomings relating to the specific context of resilient landscape design. They do not take into account all phases of an urban landscape design process including, ideation, design and evaluation and they obviously do not provide more specific tools for resilient landscape design and evaluation since they have not been developed with this goal in mind.

*Collective Intelligence Systems*

In the larger context of digital participatory design, there are specific theories and approaches for operating collective tasks. Collective Intelligence Systems are among these powerful approaches that are rarely used in landscape design process. The rise of internet technology has brought new forms of collaboration of loosely organized people for collective goals ranging from writing an encyclopedia (such as Wikipedia) to product design (such as Treadless) (Malone et al. 2009). Collective intelligence is one the most useful term\(^3\) for this new mode of organizing work and is “defined very broadly as groups of individuals doing things collectively that seem intelligent” (Malone et al. 2009, p. 2). Altee (2014) defines collective intelligence as the “the ability of groups to sort out their collective experience in ways that help to respond appropriately to circumstances - especially when faced with new situations” (Sanoff 2011, p.14). This definition relates to the concept of resilience and complex adaptive systems that have the ability of adaptation and self-origination in new situations. The concept of collective intelligence also has close affinity with community participation in design and planning. It has been mentioned as an underpinning concept of deliberative democracy and “being partly responsible for favorable participatory design outcomes” (Sanoff 2011, p.14).

\(^3\) Other terms such as crowdsourcing have been used in the literature and I use it interchangeably in this thesis document.
Despite use of collective intelligence systems in a wide variety of realms, this potential has not been explored in landscape architecture. This thesis takes a deeper look at the benefits that collective intelligent systems can offer for participatory design of resilient landscapes.

There are three main types of collective intelligence systems: directive, self-directive and passive crowdsourcing. In directive crowdsourcing, a single individual designs the system, recruits and guides participants toward a specific goal that the designer had in mind. For example, a requester\textsuperscript{4} might ask a crowd to tag images with labels or to translate a poem. Since in this type of crowdsourcing a task might often be decomposing into micro-tasks, workers may not understand how their contribution serves the broader goal and this may result in low quality of work (Bigham et al. 2014, p. 2). One example of directive crowdsourcing is Soylent, a Microsoft Word Plugin for crowdsourced editing of text documents. Soylent introduced Find-Fix-Verify (FFV) workflow which consists of three steps: 1) one group of participants locate the areas in the text that can benefit from improvement. 2) a second group of participants make changes to the allocated areas to fix the problems 3) the third group evaluate the changes that have been made and verify if they have been good changes. The workflow encourages many people to find the problems, thus more issues can be fixed. It also encourages independent evaluation which result in higher quality outcomes (Bigham et al. 2014, Bernstein et al. 2010).

In self-directed crowdsourcing, “the participants gather [relevant information] based on a shared interest, decide what to accomplish, and then do it” (Bigham et al. 2014, p. 1). In many cases, this type of crowdsourcing is based on volunteerism and non-monetary incentives for participants. There are several factors that are important in designing and understanding self-directive crowdsourcing systems such as coordination, conflicts, participation and creativity among others (Bigham et al. 2014). Studies have shown that crowds in these systems can undertake substantial coordination tasks in case of major disaster such as earthquake and flood (Bigham et al. 2014). Participation is also an important factor in these systems. Experience shows that emphasizing individual contributions and creating achievable challenges result in higher participation (Bigham et al. 2014).

\textsuperscript{4} In crowdsourcing we might differentiate between two broad classes of users: requesters and crowd workers. The requesters are the individuals or group for whom work is done or who takes the responsibility to aggregate the work done by the collective. The crowd worker (or crowd member) is one of what is assumed to be many people to contribute (Bigham et al. 2014, p. 1).
In order to evaluate the applicability of collective intelligence systems to design problems, we need to take a deeper look at the relation of creativity and collective intelligence systems. Creativity is an important part of collective intelligence systems and successful examples have articulated “a clear vision and communicate frequently with participants” (Bigham et al. 2014, p. 8). One example of use of collective intelligence systems for creative work is Ensemble. Ensemble (Figure 2) is a platform for crowdsourced storytelling that combines the strength of individuals’ and crowds’ creativity. Here a leader directs a high-level vision and articulates creative constraints for the crowds. Within this structure, the crowds can contribute in storytelling process (Kim et al. 2014).

In passive crowdsourcing, the crowd may never meet or coordinate but “an algorithm extracts meaning from logs of the workers’ naturalistic behavior” (Bigham et al. 2014, p. 1). For instance, the Livehoods project uses foursquare checkins to detect geographically based communities which in many cases are different from the “labeled neighborhoods on a map” (Bigham et al. 2014, p. 10). In this project, the mining of chekins patterns aims to reveal real dynamic of the city.

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5 http://www.livehoods.org/
Collective Intelligence Systems: Two Relevant Cases to Landscape Architecture

Collective intelligence has been seen as a problem-solving model applicable in many kinds of problems and specifically wicked problems (Brabham 2010, Introne et al. 2013). Thinking of design and planning as a collective problem solving activity (Simon 1996, Batty 2013), collective intelligence systems offer great potentials for “harnessing creative solutions of a distributed network of individuals” (Brabham 2010). The following two case studies utilize these potentials. The first case study, Climate CoLab is a large-scale open call for addressing the problem of climate change. The second case study, Crowdsourced Green Infrastructure, brings concept of collective intelligence to a different scale of design.

Climate CoLab

This MIT project is inspired by the collective intelligence experiences such as Wikipedia and proposes a global online platform for collaboratively creating, analyzing and selecting proposals for combating climate change (Introne et al. 2013). The crowdsourcing method has been chosen due to scale, complexity and open-endedness of the phenomenon. The authors believe that these characteristics of the problem require answers beyond the traditional technological solutions and needs socio-computational systems that can combine the efforts of very large groups of people to solve complex problem (Introne et al. 2013).

In developing the platform, three challenges have been addressed: “breaking the problem into pieces and subsequently recombining solutions, predicting the impacts of proposed solutions and selecting good solutions” (Introne et al. 2013, p.46). The platform consists of a series of designed contests (Figure 3) and call for proposals and a structured decision-making process to achieve good solutions. The structure of the contests and selection project/process is inspirational for developing other collective intelligent system for planning in large scales.

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6 http://www.climatecolab.org/
A Framework for Crowd-Sourced Green Infrastructure (GI) Design

This work is based on a NSF-funded research in-progress at the University of Illinois at Urbana-Champaign. The project develops “interactive methods for crowd-sourcing model parameterization and GI design. A computational, GI design framework that integrates interactive, neighborhood-scale, collaborative design by multiple stakeholders (“crowd-sourced” design) with multiscale models of ecosystem and human impacts” (Rivera et al. 2014, no page number). The project's potentials include incorporating diverse input in early stages of design which is necessary for design acceptance and incorporating integrated scales in designing green infrastructure systems.

The outline of the framework can be seen in the figure 4 below.
The research is an interdisciplinary collaboration (landscape architecture, civil engineering and computer science) and its technical details are beyond the scope of my thesis. However, the paper provides useful methods for synthesizing “input from multiple stakeholders and designers and build consensus” (Rivera et al. 2014, no page number). The methods include use of a multi-objective genetic algorithm (GA) for generating alternatives (based on human and ecological factors) for stakeholders to evaluate and rank aggregation techniques.

Despite advances in collective intelligence systems and the potentials of internet-based participatory design, I was unable to find projects that explore these systems for participatory landscape design at site scales. Many of the online participation precedents are focused on larger scale and do not consider the physical embodiment of the planning/design decisions. This might be due to the complexity of getting stakeholders inputs in design details or unwillingness of designers to go beyond design as a “self-centered creative activity”.

Due to the self-organizing character of collective intelligence systems, they have the potential to evolve through time and adapt to new conditions. They can go beyond the limitation of traditional public meetings in participatory urban design and provide opportunities for managing large or diverse group of people across geographical entities. In this context using collective intelligence systems in urban landscape designs reinforces the resiliency of the designed systems in two different ways. First, in the process of shaping resilient landscapes, they can leverage the aggregated efforts of many participants which is necessary to create resilience in multiple scales of urban systems. For example, in the case of green adaptive infrastructure, we need to have large group of citizens collaborate to shape a series of distributed but connected rain gardens. This would be more achievable if we have an underlying socio-computational structure that can
initiate and connect these green spaces. Second, in case of facing a shock, the designed systems can respond and adapt more quickly due to social infrastructure that the collective intelligence system provides for coordination and participation and complex problem solving.

Social Physics

To form resilient communities, we need social structures that are cooperative, productive and creative. In reality, we are not creating these communities from scratch but we transition to more resilient communities. This transition requires both idea flow and behavior change. These inquiries are at the center point of social physics research. “Social physics is a quantitative social science that describes reliable, mathematical connections between information and idea flow on the one hand and people’s behavior on the other” (Pentland 2014, p. 4). Idea flows within social networks can be separated into exploration (finding new ideas/strategies) and engagement (getting everyone to coordinate their behavior) (Pentland, 2014, p. 15). “Engagement is social learning, usually within a peer group, that typically leads to the development of behavioral norms and social pressure to enforce those norms” (Pentland, 2014, p. 19). Social learning is highly influential in adopting new ideas and behavior change. “Engagement with and learning from others, along with the mutual sharing and vetting of ideas, generate the collective intelligence” (Pentland 2014, p. 44).

Behavior change can be facilitated through social network incentives. In comparison to economic incentives, social network incentives focus on the social context in which the individuals are situated rather than rewarding the individuals themselves (Figure 5). Here the focus is on changing the connections between people rather than individuals’ behavior change (Pentland 2014, p. 69). These incentives facilitate idea flow through social pressure and increasing interaction around specified targeted ideas and therefore they increase the likelihood of behavior change (Pentland 2014, p. 66). For example, the Funfit project proves the effectiveness of this approach.

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7 Social learning is how new ideas become habits, and how learning can be accelerated and shaped by social pressure.

8 Social pressure is the negotiating leverage one person can exert upon another, which is limited by the exchange value between them.
In this project, “everyone in the Friends and Family study was assigned two buddies...” Since nearly everyone in the community was involved, each participant was also a buddy for someone else, and thus everyone had opportunities to be both a behavior-change target and a buddy. The first step to deploy FunFit was to create clusters within the existing social network that were centered around each target person. The members of the cluster are called buddies (the light gray people in Figure 4), and they are given a small cash reward based on the behavior of the central target person (the dark gray people in Figure 4, labeled A and B) during the previous three days. This arrangement creates social pressure to be more active by providing incentives to the people who have the most interaction with the targets and rewarding them rather than the targets for improved behavior. In other words, our social network incentives promote engagement— repeated cooperative interaction among members of the team— around ideas about how to be more active. ...On average, it turned out that the social network incentive scheme worked almost four times more efficiently than a traditional individual-incentive market approach.... People who received social network incentives maintained their higher levels of activity even after the incentives disappeared. The number of direct interactions that people had with their buddies was an excellent predictor of how much their behavior would change” (Pentland 2014, p. 67).

In addition, social pressure can result from comparison of the individuals with the people that are relevant to them both in terms of the amount of interactions they have with each other or the affinity of their geographical and interest contexts. In this regard, targeted visualized data

Figure 5: Reward system diagram: By confining incentives for good behavior to the local social network (the social ties in the dark ovals), social pressure is brought to bear on the target individual. This method works. Source: (Pentland 2014, p. 67)
comparing the individuals' and their relevant people's performances are seen as incentives for behavior change.

Idea Flow and Social Interaction in High-stress Situations

Social pressure as the incentive for behavior change is also a useful approach in high-stress situations (such as the aftermath of natural disasters) since adapting to new conditions requires creating and enforcing new habits of interaction (behavior change). For more effective disaster management, we should see our urban systems as self-regulating dynamic systems and not static systems that are separated by sectors such as water, food, waste, transport, education, energy, and so on. The urban systems should be driven by “preferences of the citizens instead of ones focused only on access and distribution” (Pentland 2014, p. 138).

Self-regulated distributed responses to post-disaster situations has proved to be very effective. Occupy Sandy is one example of this approach where the organization created a framework for engagement rather than assigning tasks to participants. In their model “response and recovery tasks had to be completed by people, often via self-selection and assignment” (Brugh et al. 2015, p. 12). Different nodes of activities were designed and people could move freely between these nodes. In addition to activity node, there were nodes with organizational purposes. These nodes include Communications, Dispatch, Distribution, Intake and Interoccupy. Each nodes function was as it follows:

- **Communications** ("comms"): performed two main tasks, one engaging in conversations online, phone, etc as attached to dispatch; the second which dealt with back-end and internet infrastructure;
- **Dispatch**: coordination of requests from the field with resources in distribution centers;
- **Distribution** ("distro"): coordinated via dispatch of incoming and outgoing volunteers, supplies, and food either to relief site nodes or directly to individual locations;
- **Intake**: held orientation for incoming volunteers to learn or demonstrate basic communication protocols, history, and interaction assumptions as well as to verify commitment and to help find need and skill overlaps;
• **Interoccupy**: coordinated between various Occupy groups, including website incubation space and OS to Occupy Oklahoma knowledge transference. (Brugh et al., 2015. p.12).

Designing a *framework for engagement* and *knowledge transfer* is crucial for post-disaster management. The same is true for co-creation of self-regulating urban systems that are resilient to changes. In this regard, the potentials of socio-computational systems for providing such a framework need to strongly considered by landscape architects and urban designers.

**Ecological Rules**

So far, we have discussed the concept of resilience and the potentials of socio-computational systems for providing the social infrastructure that resilient communities need. However, this section will focus on concept of ecological resilience in the specific context of urban planting under climate change scenarios. In narrowing down the context we have already answered the question of “what needs to be resilient”. Within this context, the thesis explores the answers to two other questions: 1) Resilience to what? 2) How does resilience occur?

The answer to the first question is straightforward. Our urban systems need to be resilient to major impacts of climate change which include “changes in temperature, sea level rise, precipitation change, and extreme events” (Blanco et al. p.159). This thesis is focused less on sea-level rise and more on other impacts of climate change. But it is in answering the second question that we acknowledge the gap in the literature on how we can bridge climate change adaptation strategies to local urban landscape design decisions. A rule-based approach is necessary to translate the adaptation strategies to site scale design and analysis solutions.

*Rule-based Ecological Design for Resilient Urban Planting*

Plants, as the living matter of designed landscapes, change regularly through the seasons. They also are affected by warmer average temperatures and extreme environmental conditions due to climate change. Although there are local nuances in their change or growth pattern through time, general rules exist that can help us to achieve a general understanding of the resiliency of the planting schemes.
There is a line of research that calls for adaptation strategies to buffer ecosystems against uncertainty resulting from climate change. Many adaptation strategies are concentrated on urban planning solutions for “sea-level rise, heat island effects, health impacts, and water treatment”, while strategies for urban planting are limited (Hunter 2011. p.174). Hunter (2011) provides a rule-based approach to urban planting resiliency through rating the plant species based on ecological criteria for plasticity, functional redundancy, response diversity, and structural diversity.

Plasticity here is in close relationship with ecological resilience and defines “how well species perform across a range of environmental conditions. Ecological resilience is defined as the ability of maintaining ecosystem function under environmental disturbance and depends on both functional redundancy and response diversity” (Hunter 2011. p.174). While functional diversity is defined as “the number of species contributing to an ecosystem function”, response diversity deals with “the range of reaction to environmental change among species contributing to the same ecosystem function” (Elmqvist et al. 2003; Hunter 2011. p.174). Structural diversity describes the “diversity of physical or architectural form within a collection of plants” (Hunter 2011. p.175).

As an example, Hunter (2011) explores a planting design with the goal of support for generalist pollinators. Here, functional redundancy can be achieved through having overlapping bloom times. For response diversity, the overall species that provide nectar should be flexible to the environmental variations such as both drought and flood events (Hunter 2011. p.175). These ecological criteria can be translated to quantifiable parameters and rules. For example, for response diversity, if we define a range of drought tolerance (zero, low, medium and high), a score of drought tolerance as a part of response diversity can be assigned for each species ranging between (0-3).

The rule-based approach can link these broad adaptation strategies to landscape design and analysis at site scale. This approach also is important in the way we increasingly use computer-aided design as a design tool in landscape architecture.
As mentioned before the literature lacks principles and tools for designing resilient landscapes at small scales. Designers’ approach in small-scale landscapes focuses more on static scenes, even when they consider factors that are more dynamic. This is mainly because design is considered as the embodiment of the ideas and analyses in a fixed form, while the reality of landscapes is dynamic and evolving (Walliss et al. 2014). Another contributing factor to inability of the landscape architects to reflect the changing nature of the landscape in the design process is the way that the discipline uses CAD.

Computer-aided design started in architecture and caused a major paradigm shift in the way it is conceived and represented (Vardouli 2011). Early in the history of computer-aided design, Yona Friedman emphasized how CAD can produce a “repertoire of possibilities” for the users to choose and allow them to see and correct the design errors. Errors can be determined based on quantitative rules in the context of design; e.g. size of the structure in an architectural design project. According to Freidman, the main potentials of CAD lie in its educative and adaptive nature and its ability to produce different design alternatives in a transparent process based on certain design rules (Vardouli 2011). This rule-based participatory approach to CAD has diminished in mainstream design for years and it has come back strongly in recent decades as the idea of rule-based, generative or parametric design.

Parametric design takes place through defining constraints/parameters of design and their relationship/dependency. Parametric tools are interactive; users can change the value of parameters (Bier, 2013; Steino et al., 2013). They can instantly visualize the change in the system and thus provide a high level of detail even in early stages of design. In the context of parametric tools, the designer will actually be able to design the rules rather than the object of design. From the simple rules, complex configurations can emerge and time-related parameters of design can help to trace the design through time.

Parametrics have been explored vastly in architecture, urban design and planning fields (Schumacher 2009). Landscape architecture has been slow to embrace new technologies to expand design processes and techniques (Walliss et al. 2014), and parametric design is not an exception. The discipline’s use of parametric design has been influenced by the conceptualization
and application of the parametrics in architecture, which is more focused on finding optimized forms. This happens while “landscape design solutions rely on transformation, growth, decay, flow, and settlement to produce evolving solutions” (Walliss et al. 2014, p.76). The need for a distinctive approach for the use of parametric design in landscape architecture is apparent considering the differences between the two fields. The changing aspects of the landscapes require a more dynamic use of parametric design.

Conclusion and Summary

Resilience is a character of complex adaptive systems and in order to achieve resilient landscape design solutions, landscape architects need to see urban landscape systems through the lens of complexity theory. However, incorporating dynamicity of complex systems in small-scale designs requires acknowledging the bottom-up social and ecological processes that shape urban landscapes in nested scales. In order to engage with these processes to direct the urban systems to a more resilient level, we need to utilize socio-computational systems such as collective intelligence systems and design the social mechanisms in these systems that provide a platform for idea flow and behavior change. The platform would help to shape more resilient communities and consequently more resilient urban landscapes. Shaping more ecologically resilient landscape also requires knowing ecological rules of resiliency. In this regard, high plasticity and redundant planting can play an important role.

Chapter 3 and 4 shows the process and the results of prototyping an example of such a socio-computational platform that utilizes CIS and ecological rule-based design approaches for providing a platform for participatory resilient landscape design.
Chapter 1: Introduction

Chapter 2: Literature Review

**Chapter 3: Method and Process**

Chapter 4: Discussion

Chapter 5: Conclusion
Chapter 3: Method and Process

Introduction

This chapter outlines the general method for this research and the basic methods used to create the online co-design application. The application is designed as a prototype illustrating how socio-computational systems and rule-based ecological design can be used for participatory design of resilient landscapes. This chapter discusses the process of application development and shows how the design of the app's components and organization reflects the theoretical foundation discussed in Chapter 2. It also mentions the data, tools and techniques that have been used for prototyping the application. This chapter also discusses the limitation and scope of my research. A full write up of the app content and scenarios of use are the result of this research and they will be presented in chapter 4.

Detailed Research Questions

The primary research question for this thesis is that what approaches and tools are helpful to design resilient urban landscapes at the site scale? This study argues that an online collaboration tool for urban design that provides both an expert system and a platform for harnessing the indigenous knowledge of people can result in directing our urban systems to a more resilient level. After exploring the relevant literature, the more detailed research questions become:

1) How can the insights gained from theories and techniques of participatory planning and design, collective intelligence systems and social physics be used to structure an online co-design tool for urban landscape design?

2) How can collective intelligence systems structure be integrated into urban landscape design processes?

3) How can social network incentives be used to motivate users to change their behavior to a more sustainable one?
How can an expert system that utilizes ecological resilience rules be developed to provide resilience evaluation for different design solutions at the site scale?

What are the benefits of using this tool for each group of users (landscape architects, citizens, NGOs, governmental organizations)?

How can this platform increase the resilience of urban landscapes?

In developing the application, these questions have been addressed conceptually and through incorporating the relevant theories and tools in the platform. The degree to which this application is a successful answer to these questions will need to be assessed through a comprehensive evaluation of the app in the context of a pilot study within an urban community. Even though this evaluation was not possible in the timeframe of this master thesis and is an important future step. A proof of concept is presented in Chapter 4.

**Definition of the Terms**

*Online Platform, Computational Platform, Co-design tool, Mobile/web application, App*

A computational platform is a piece of software that runs on personal computers or mobile devices. The online platform refers to software applications that substantially depend on accessing the World Wide Web to operate. In this document, the term online platform is used interchangeably for the co-design tool, the application and the app; all refer to the computational platform that is the outcome of this research.

*Collective intelligence Systems*

Altee (2003) defines collective intelligence as the “the ability of groups to sort out their collective experience in ways that help to respond appropriately to circumstances - especially when faced with new situations”.

*Social Physics*

“Social physics is a quantitative social science that describes reliable, mathematical connections between information and idea flow on the one hand and people’s behavior on the other” (Pentland, 2014, p. 4).
**Expert System**

“Expert systems (ES) are a branch of applied artificial intelligence (AI), and were developed by the AI community in the mid-1960s. The basic idea behind ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. The computer can make inferences and arrive at a specific conclusion. Then like a human consultant, it gives advices and explains, if necessary, the logic behind the advice (Turban & Aronson, 2001).” (Liao, 2005, p.93)

**Small Scale**

We need to define this term since it has different meanings in different fields such as geography, architecture, urban planning and landscape architecture. In this document small scale design is design at community and/or site level. This includes both private spaces (like backyards) at site level and public spaces (like community gardens) at neighborhood level.

**Limitation and Scope of the Research**

Providing a comprehensive framework for context specific participatory resilient landscape design requires exploring site-specific ecological details and urban system analyses that are beyond the timeframe and scope of a master thesis. In order to make the research manageable, the primary research question - which is to search for helpful approaches and tools to create resilient urban landscapes- is narrowed down to four different levels. First, this thesis identifies relevant computational tools and approaches for site scale resilient landscape design. This focus is mainly chosen because of ever-increasing use of computational tools in both professional landscape design process and community-engaged design and planning. Despite this increasing use, many current available computer-aided design tools do not incorporate dynamic social and ecological factors in the landscape design process that are essential to resilient design solutions. In addressing this gap, this research introduces less- explored computational approaches and tools that are helpful for incorporating idea of resilience in design at site scale.

Second, among the different scales of resilience analysis, this thesis focuses on site and neighborhood scales while not overlooking their relationships with larger scales. Third, among
many aspects of landscape design including hard scape design, this research focuses on urban planting. This aspect has been chosen for two reasons: i) the knowledge in this field can be easily parameterized and turned to an expert system relative to other aspects of landscape design and ii) the large datasets showing the characteristics of many different plants needed for developing a resilient landscape design are available online. Here, it is important to emphasize that this research does not intend to incorporate all nuances of site-specific planting design to an expert system. However, it can be seen as a departure point for the designers through providing some resilience-related general evaluations. Fourth, although the target of the research is beyond a specific location and it explores general social and ecological processes, in order to situate the research in a sample context for understanding the way it can be used, the city of Philadelphia is chosen as a sample location. As mentioned before since many aspects of this research are beyond a location, this thesis is not going to delve into an in-depth exploration of Philadelphia’s social and ecological contexts.

Synthesizing literature in different fields, such as computer and environmental science, into a framework to be applicable in landscape design process is a difficult task. Due to the interdisciplinary nature of the research, some important technical aspects of each field are probably going to be missed. It is important also to emphasize that some terms in this document may not been used by their exact definition in other fields. For example, expert system development in this research does not incorporate the rigid definition and processes in computer science. Here, it is loosely defined as a computational platform that incorporates partial knowledge of urban planting and provides suggestions to the users. This interdisciplinary research has been challenging due to the lack of literature that links system thinking, resilience, CAD and landscape design. As a result, this research is exploratory and subject to revision through future work.

The main motivation beyond the research is to provide landscape architects an alternative approach and tool for resilient design at site scale; and a platform for active use of bottom-up social and ecological processes for directing our urban system into a more resilient level. Here, the role of the landscape architect is not conceptualized as the traditional “designer” but as a design expert who actively helps to develop such platforms, who analyses the performance of the co-designed urban landscapes, evaluates gap in the system and directs the social network to a more resilient step. In this thesis, the focus is more on designing such a platform for citizens
and not on the role of landscape designers. This thesis argues that the urban landscape design process will be transformed through use of technology and landscape architects and environmental designers should be part of this transformation. Software engineers and information scientists already have designed software applications that influence social and ecological processes of the urban landscapes and the knowledge of our field is missing in this relevant context. This underscores the need for landscape architects to go beyond being passive consumers of computational tools and incorporate their interdisciplinary knowledge into the development of computational tools needed for resilient landscape design.

In the timeframe of this master’s thesis, I have focused on exploring and synthesizing the relevant approaches and tools and developing a prototype of the application. As mentioned before, an important next step will be the testing of the prototype as a research tool with participants groups.

**General Research Approach**

The primary goal of this research is to provide an alternative approach for designing resilient urban landscapes at the site scale that directs bottom-up ecological and social processes for increasing the resiliency of urban systems. This thesis uses “making as a method of inquiry in order to address wicked problems” (Zimmerman et al., 2007, p. 496). Here the wicked problem is how to facilitate collective efforts for increasing resilience of our urban landscapes; while the creation of the artifact (co-design tool) represents the “making” component of the method. In addressing the problem, first, I have identified the potential that using computational theories and tools such as rule-based design, social networks incentive design (social physics) and collective intelligence systems provide for catalyzing sustainable behavior in communities to achieve resiliency goals at multiple scales. Second, through the process of ideating, iterating, and critiquing potential solutions, I have developed a prototype of an online co-design tool as a research artifact that embodies the identified theoretical and technical potentials (Zimmerman et al., 2007). The way that the tool utilizes these potentials are explained in the next section of this chapter.
Tool Development Method

As mentioned earlier, the general methodology for this study is *making* as a way of inquiry. The first step in the platform development was innovative incorporation of the studied theories (CIS, Social Physics and Ecological Rule-based Design) into the structure and the components of the online platform. The general map of these relations are depicted in Figure 6. This thesis proposes an IT-assisted participatory landscape design framework that consists of a collective intelligence system and an expert system.

![Proposed IT-assisted participatory landscape design framework](image)

**Figure 6: Proposed IT-assisted participatory landscape design framework.** The platform consists of two main parts: a collective intelligence system and an expert system. In developing the CIS part, I have used the theories of CIS, social physics and participatory urban planning and design. In developing the expert system, the main relevant theory is ecological rule-based design. In this framework people participate in design process through using the CIS. Landscape architects participate in developing the expert system that provides a resiliency evaluation of citizen designs. People in return feed the expert system by their evaluation based on their local experience. These secondary evaluations can be used for refining the expert system.
The co-design tool provides designers, citizens and organizations a platform to: i) *Initiate* projects through finding potential sites, ii) *design* and *evaluate* landscapes and iii) *share* their knowledge, experiences and even materials/tools needed for their projects. Collective project *initiation, design* and *evaluation* and *sharing* knowledge and materials are done in the proposed collective intelligence system and social network part of the co-design tool. However, among these different tasks, in *evaluation* of different design solutions, the expert system plays an important role. The tool analyzes the different project sites through accessing large online climate analysis tools that provide an estimation of the sites' risk of different extreme events caused by climate change such as flood, sea level rise, drought and extreme heat events. The tool also evaluates citizen-designed planting schemes based on ecological resiliency rules and shows the performance of the plans under different scenarios of extreme environmental events.

Overall, through informing users by means of visualized data related to their resources and performance and social mechanisms such as peer pressure, the tool aims to catalyze behavior change and citizen engagement in the design process for reaching collective urban resilience objectives. As mentioned before, the platform consists of a collective intelligence system and an expert system. From these two parts of the platform, the expert system is developed in greater detail since it reflects the expert knowledge in landscape architecture and it examines how we can use ecological rules and parametric design to inform design decisions at site scale. The full write up of the app structure and components are discussed in Chapter 4, but here I explain the methods that have been used in the development of the collective intelligence system and expert system.

**Collective Intelligence System Development Methodology**

This research uses a combination of all three crowdsourcing systems discussed in the previous chapter including *directive, self-directing* and *passive crowdsourcing*. Here, inspired by *directive* crowdsourcing FFV (Find-Fix-Verify) method the landscape design process is divided into three main steps. In FFV method, we have three steps (Find-Fix-Verify) that are assigned to three different groups of people. In this thesis the proposed landscape design framework process is divided into three different steps of *Initiation, Design* and *Evaluation* and instead of assigning all of these tasks to one individual or single group of people, different people can voluntarily work
The proposed framework for collective intelligence system development is also inspired from applying such systems for creative work such as Ensemble experience in which an individual can start a creative project and ask crowd to participate in shaping some components of the story. In our platform, a person can start a green space project and ask other people to participate in design or evaluation stages. The detailed description of the components of this part is discussed in Chapter 4.

Although using a directive crowdsourcing method for the design component of the tool, this platform is mainly a self-directing crowdsourced system since it is not based on a single requester and requires the process of coordination and participation of groups of volunteers. In the system development, non-monetary social network incentives such as peer pressure are used to reach higher participation rates. Finally, the system can also be considered as a passive crowdsourced system since the data that the users of the tool create about the potentials and the problems of their surrounding built environment can be independently analyzed to discover the pattern of people preferences and the conditions of the built environment. This can be inferred from the potential projects that people initiate or the problems they tag in their neighborhood.

**Expert System Development Methodology**

As previously mentioned before, the basic idea behind the expert systems is “that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer” (Liao, 2005, p 93). Expert Systems (ES) are increasingly used in software applications in different domains where their role is critical in the process of decision support and problem solving (Liao 2005). ES methodologies are classified in different categories such as rule-based systems, knowledge-based systems, neural networks, fuzzy ESs, object-oriented methodology, case-based reasoning (CBR), system architecture development, intelligent agent (IA) systems, modeling and ontology (Liao 2005). Although some of these methodologies have common concepts, this thesis mainly uses rule-based system as the methodology of expert system development.

“A rule-based ES is defined as one, which contains information obtained from a human expert, and represents that information in the form of rules, such as IF–THEN. The rule can then be used to perform operations on data in order to reach appropriate conclusion. These inferences are essentially a computer program that provides a methodology for reasoning about
information in the rule base or knowledge base, and for formulating conclusions” (Liao 2005, p. 94).

This methodology is an appropriate choice to turn the knowledge in rule-based ecological approach in landscape design that is discussed in chapter 2 to a computational system. It is also well-suited to urban planting (as the focus of this research) in which ecological resilience knowledge can be turned to the form of “IF-THEN” (“conditional”) rules. In addition, this methodology has been chosen due its easier implementation process. However, it should be noted that due to the uncertainty in the process of urban planting by multiple users, more flexible approaches such as Fuzzy ES should be examined for future applications. The more detailed explanation on the rules and the data used in the expert system development are discussed in Chapter 4.
Chapter 1: Introduction
Chapter 2: Literature Review
Chapter 3: Method and Process
Chapter 4: Discussion
Chapter 5: Conclusion
Chapter 4: Discussion

Introduction

This chapter discusses the result of this study. This research produced a co-design tool prototype relying on theories of collective intelligence systems and ecological rule-based design. The process of tool development can be summarized in four steps.

1) Searching for relevant computational theories and tools,
2) Developing a resilient landscape design expert system in Processing programming language,
3) Developing a prototype of the co-design tool and scenarios of use, and
4) Validation of the prototype tool.

Although the fourth step is needed for the completion of the tool development process, it was not feasible due to the aforementioned complexities of the research within the timeframe of an MS thesis. The result from step one is presented in chapter 2 in which I discussed relevant literature. The second step is an important part of the research development process in which I developed algorithms and codes in Processing programming language to depict how rule-based ecological design can be turned to a computational expert system for resilient landscape design and analysis. The result of this step will be published as a paper in the Digital Landscape Architecture (DLA 2016) conference journal. Although this step is a very important milestone in the process of this research, in order to stay more focused on the final prototype, the full paper discussing the second step is attached this document as Appendix I.

This chapter mainly focuses on the third step outlined above. In discussing the third step, it explains the structure and components of both the collective intelligence and expert systems parts of the co-design tool and describes the scenarios of use and the way in which the application can help to achieve a higher level of resilience in our urban systems. At the end of the chapter, I will address the question of how wide-spread use of the online platform can result in more resilient urban landscapes. The question addresses the fourth step (tool validation).
Structure and Components of the Co-design Tool

As mentioned in Chapter 3, the co-design tool consists of a collective intelligence system/social network and an expert system (Figure 6). While all four tasks of initiation, design, evaluation and sharing shape the CIS/social network, evaluation is at the center of the expert system. This section explains the components and structure of each part in detail.

Collective intelligence system and social network

According to Malone et al. (2009), building blocks (“the genes”) of CIS are derived from answers to four fundamental questions: 1) Who is performing the task? 2) Why are they doing it? 3) What is being accomplished? And 4) How is it being done? Here, I address the third and fourth questions, while I discuss the first two questions in the Scenarios of Use section. Specifically, this section discusses design and sharing as the central tasks that are being accomplished in the proposed CIS (what is being accomplished?). It also investigates how these tasks can be performed (How is it being accomplished?).

As discussed in Chapter 2, collective intelligence systems have been used for a wide variety of creative tasks such as product design or creative writing. However, their direct use for urban landscape design is unprecedented. Design in general is an iterative non-linear process and is “best described metaphorically as a system of spaces rather than a predefined series of orderly steps. The spaces demarcate different types of related activities that together form the continuum of innovation” (Brown, 2008, p.4). Here, this thesis discusses briefly the similarity of the design process across variety of domains including product and landscape design. Then it correlates these design processes with FFV (Find-Fix-Verify), a method of crowdsourced text-editing, since the benefits of this method is relevant to participatory urban landscape design processes.

Design Processes and Collective Intelligence Systems

Design thinking is an approach to innovation that explains that most design projects go through three steps of inspiration, ideation and implementation. While inspiration is the problem and/or the opportunity that motives the search for solution, ideation is the process of generating
and testing the ideas that lead to solutions and implementation ensures that the solution would become a reality in the market (Brown, 2008).

While design thinking literature is mostly shaped in the context of product and software design and management practices, it is similar to the same general path followed in architectural and landscape design processes: departing from problem/opportunities to a solution through the steps of inspiration, ideation and implementation. There are several ways of describing the landscape design process. While this research is not aiming to explore this literature, it is helpful here to mention a typical landscape design process based on Toth (1988). The landscape design process consists of: 1. Pre-analysis (problem formulation), 2. Data inventory 3. Full-scale analysis, 4. Criteria-evaluation development, 5. Concept development, 6. Concept evaluation and selection, 7. Site planning, 8. Site Design, and 9. Implementation. These nine steps (or spaces) can be summarized into four main categories: problem development, concept development, concept evaluation and implementation. As we can see, the problem development is aligned with inspiration space of the design thinking process, as the concept development and evaluation match the ideation space, and the implementation space is common in both processes.

This thesis finds an interesting correspondence between the aforementioned design process and a method of doing collective tasks in CIS: FFV (Find-Fix-Verify). As discussed in chapter 2, in the context of text-editing, FFV method allowed participants to identify and thus fix more issues. It also encouraged independent evaluation that results in higher quality outcomes. The same benefits can be true in the context of urban landscape design process. In many cases, outdated data on citizens' needs and issues results in urban design projects that do not reflect their current immediate potentials and problems. Even in many cases of a traditional participatory planning and design process, participants work on a pre-defined project without having a chance to identify the problems and potentials and thus define the relevant projects. In other cases, the time and size of public meetings do not allow for extensive brainstorming that links the immediate needs of the residents to defining relevant projects that addressees the potentials and problems of their urban context. Therefore, the Find step in FFV method in which a group of participants are assigned to find issues can have an equivalent step in a crowdsourced landscape design process in which citizens are assigned to find the potentials and problems of their neighborhood without being biased or bounded by providing solutions to those issues. This step (space) in my proposed CIS framework is called initiation. The Fix step in the FFV method can be
translated as a design step in crowdsourced landscape design in which citizens provide solutions to the projects that their fellow citizens have defined. In this step, people receive resilient design tips and strategies from the expert system of the application but they are free to explore different solutions. Lastly, the verify or its equivalent in crowdsourced landscape design – evaluation, is where both CIS and ES are integrated to vet the solutions in terms of their resilience level. In this step, the expert system provides resilience evaluation. The details of the expert system will be explored in the next section of this thesis. In addition to evaluation of the expert system, people also provide their feedback and knowledge on how, and to which degree, a planting scheme is resilient – based on actual experience. The citizens’ feedbacks in addition to the expert system evaluation shape a more comprehensive and nuanced site-specific evaluation of the solutions and the (user) feedbacks are used for refining the expert system.

Figure 7 depicts the relationships between the design process in design thinking, landscape design and FFV method. It also depicts the proposed crowdsourced co-design process in landscape design. Figure 8 shows the home page interface of the prototype of the online platform. It shows the three spaces of crowdsourced design in three different levels: individuals, friends and neighborhood. Figure 9 through 13 show how a user can initiate a project in the neighborhood in the prototyped tool; he/she can choose a place and drag and drop the location mark to the place, then the user can choose a title, write a proposal for the project. Then he/she can open to design and evaluate. The user also can browse the initiatives that other community members have started and read their proposal and if it is open for design or evaluation participate in those steps.
Figure 7: Comparison of different steps (spaces) of Design Thinking, Landscape Design and FFV process. Each space or step of proposed co-design or crowdsourced process in landscape design corresponds with some steps of the aforementioned processes.

Figure 8: Homepage of the online co-design tool showing the three steps (Initiate-Design-Evaluate) at three levels (individuals/me-friends-neighborhood)
Figure 9: **The Initiate step in the prototyped application.** This part shows the projects the user have started and allows for initiating new project by drag and dropping the location icon. The previous projects are shown under “your initiatives” title.

Figure 10: **User interface of the initiation step:** The user can decide if she/he wants to start a rain garden or a vegetable garden. She/he can write a proposal and make it open to design or evaluation or both. When the user hits the “plant the seed” button the project will be added to the user’s initiatives.
Figure 11: **User interface of the initiation step**: The user also can see other members’ initiatives. The ones with red borders are the user’s initiatives. If the individual is interested in design or evaluating a project that is open to that step, he/she can choose it and go to the project page.

Figure 12: **User interface of the initiation step** User can read the project’s proposal and then click the design or evaluate buttons.
Crowdsourced Landscape Design and Social Physics: Reward system, Data Visualization and Sharing system

As mentioned earlier - **Initiation, Design and Evaluation** are the steps of the proposed crowdsourced landscape design process. The relationship of these spaces to the CIS and ES parts of the application is depicted in Figure 13. In this framework citizens and landscape architects participate in the initiation and design steps of the processes through a CIS platform. ES provides evaluation of the design solutions and participants also provide feedbacks on ES generated evaluations and add their indigenous/local experiences and knowledge.

![Diagram](image)

*Figure 13: Three spaces of crowdsourced landscape design in regard to CIS and ES*

The important question that ties the CIS development processes to the literature in social physics is how we can motivate communities in neighborhoods to use this CIS for achieving their collective goals. According to the social physics literature mentioned in Chapter 2, rewarding friends/buddies of individuals is very effective in fostering a behavior change and collective work in a sample society. Another important technique is to provide peer pressure through comparing an individual to the people that matter to him/her and also those people that the individuals can relate to them due to their shared geographical or cultural context.
In order to implement these ideas in the proposed CIS platform, three levels of *individuals*, *friends* and *neighborhood* are considered for incorporating a reward system and also visualization data related to the performance of each of these levels (Figure 8). In the proposed CIS, individuals and their friends can be rewarded for contributing to different tasks such as their contribution to each step of design (*initiation, design* and *evaluation*) or *sharing* process. Users also can be rewarded based on the degree to which they or their friends’ or their neighborhoods’ designed spaces performance meets the individual or collective resiliency goals. There are two types of rewards: contribution-based and performance-based rewards.

For example, in a contribution-based reward scenario, an individual who *initiates* a green project, can collect some points. The process is the same for other tasks of *design* and *evaluation and sharing*. If the individual receives certain points, for example, 10 contributions in the *initiation* step, she and her friends receive a reward. The reward can be non-monetary, for instance virtual badges. In certain communities, some financial mechanisms can be devised for monetary rewards. For instance, a small portion of the profit from selling a community garden’s crops can go to this system for encouraging more efforts to implement green infrastructure and increase the resiliency of the neighborhood. The weight of different rewards should be different to encourage collective efforts. For example, neighborhood resiliency badges are much important and prestigious than individuals’ resiliency badges.

In a performance-based rewarding scenario, the individuals (and his/her friends) who implemented a garden which has a certain degree of resiliency score based on the expert system evaluation can receive a reward. The reward also can be allocated based on the actual performance of the designed garden under severe environmental conditions such as a drought in the region.

In addition to the reward system, another important strategy to create peer pressure and motivate people is to compare the performance of individuals’ gardens based on resiliency rules. As Figure 8 shows, resiliency scores are calculated for designed landscapes in three levels of individuals, friends of individuals and neighborhood level. The details of score calculation at each level is discussed in the Expert System section of this chapter. In addition to providing peer pressure having the score in three nested scales provide a complexity thinking perspective in which we can aggregate and evaluate the resilient individual designs and trace their effects on
larger scales. This also reveals the collective results and provides the community a mean to evaluate their performance as a whole.

A sharing system is also an important mean for community building through use of the online platform. People will share their evaluation of designed landscapes, their experiences regarding their implemented gardens and also the tools and the materials that are needed for implementing the project. The users can inform each other through sharing the relevant quantitative data regarding their gardens such as yield. The platform also can use the local NGOs more actively and ask them to distribute environmental sensors to different community members. Consequently, the tool can visualize the network of environmental data resulting from the distributed sensors. Other activities and events should be defined in the app in order to connect the virtual community to real-world collective problem-solving processes. In this regards, NGOs can be very effective local agencies for facilitating events and community building activities. This is particularly important since it increase the flow of information in the community and thus facilities more green initiatives in the neighborhood. Figure 14 shows the sharing system of the prototyped co-design tool.
Expert System

The expert system part of the co-design tool is mainly involved in the evaluation step of the crowdsourced landscape design process. As mentioned in chapter 3, this thesis uses a rule-based approach to expert system development. Here, the knowledge of resilient ecological design is used to develop a series of rules that helps to produce both pre-design and post-design evaluation for the users. Pre-design evaluation is based on the location of the project and provides information and strategies for resilient design in that particular location. Post-design evaluation is the process of calculating resiliency related scores including plasticity and redundancy scores for each designed planting scheme. The following sections explain these two parts of the expert system in detail.

Pre-design Evaluation

As mentioned before, the major impacts of climate change include “changes in temperature, sea level rise, precipitation change, and extreme events” (Blanco et al. p.159). However, the importance and degree of these changes differs from site to site. In providing location-based design strategies, it is important to target the changes that are more relevant to the project site. In the pre-design evaluation component of the expert system, the application gets the location of the project site as an input and accesses online existing climate analysis tools. These online climate analysis tools include Climate Change Scenarios, Climate Explorer and Cities Impacts & Adaptation Tool. A brief description of each tool has been attached as Appendix II to the end of this document. Each of these tools are used for a particular purpose. Climate Change Scenarios is used for having an understanding of temperature change in the site. Figure 15 shows an example of pre-design evaluation. In this example according to the “Climate Change Scenarios” tool, the sample site will experience a 2.1-degree temperature rise between the period of 2014-2034. This makes heat tolerance a relevant factor in species selection and thus the Expert System will provide this strategy for the users. The Climate Explorer tool has been used for variety of site-specific analyses. They include drought, flood and sea level rise. In our example (Figure 15), based

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9 https://gisclimatechange.ucar.edu/inspector
10 http://toolkit.climate.gov/climate-explorer
11 http://graham-maps.miserver.it.umich.edu/ciat/
on Climate Explorer analysis, the site has been prone to both projected drought and sea level rise. In this case, the expert system checks the condition, if the site is in the drought and flood risk areas, and then generates design strategies for considering both drought and flood tolerant species. The Cities Impacts & Adaptation Tool has been used for creating a tie to the social structure of the co-design platform. This tool defines “Climate Peers” for each given site. Climate Peers are the regions that experience similar climate conditions as the given site’s projected (impacted by climate change) conditions for the period 2040 – 2070. The proposed ES uses the climate peer areas for connecting people around the project site to the Climate Peer Friends that are already living in the projected condition. This can be immensely helpful for getting access to the experience of people on what type of the species would be resilient under those conditions. Connecting with climate peer friends can also facilities a smooth transition and adaptation to climate change. The ES also checks if the project site is in an urban area, and if so it generates a design strategy for considering shade resistant species.

Figure 15: Pre-design evaluation: Showing the different aspects of climate analysis for the project’s site. The analysis includes risk of temperature increase, flood and drought. The ES also introduces peer climate regions and analyzes if the site is in an urban area.
Post-design Evaluation

After the users receive pre-design evaluation, they can design their planting schemes (Figure 16). The application provides a repository of resiliency-tagged plant species in three main categories: trees, shrubs and grass. The resiliency tags include flood-resistant, drought-resistant and shade-resistant properties. The resiliency tags are devised to connect the strategies that the user received from the pre-design evaluation to their design decisions. After the user designs the planting schemes, the expert system goes through the series of resilient ecological tools to calculate three resiliency related scores of plasticity, redundancy and tolerance (Figure 17). The algorithms and the data used for calculating each of these scores as follows.

Figure 16: Post-design evaluation: The design component of the application. The user can drag and drop the plants in the site and design their gardens.
Data

A comprehensive plant database is needed that includes the values of at least the following characteristics: hardiness zones, soil type, soil moisture levels in which the plant survive, flood tolerance, drought tolerance, heat tolerance, the month that the plant is in bloom, and bloom color. Other characteristics such as fall color, plant’s minimum and maximum size also can be helpful. The USDA plant database\(^{12}\) has some of these characteristics. The related tags on the USDA plant database include flower color, bloom period, drought tolerance, shade tolerance and moisture use. The associated hardiness zones and the exact bloom start and end month need to be added to the plant data. The bloom start and end months range from 1-12 representing the months of the year. The hardiness zones range from 1-9. The number of the hardiness zones in which the plant can survive represents its tolerance to temperature variations and is labeled as

\(^{12}\) [http://plants.usda.gov/dl_all.html](http://plants.usda.gov/dl_all.html)
heat tolerance. The heat tolerance is calculated from the row data available in USDA plant database (the hardiness zones in which plant survive) and is added to the plant database and is represented with the range of 0-3 where 0 represents no tolerance and 3 represents maximum tolerance. Other data that cannot be calculated form the row data in the USDA database will need to be added to the app's database gradually from other sources such as universities and individual researchers' plant databases and NGOs working on gathering plant data.

Algorithm for Calculating Resiliency Scores

**Tolerance Score**

The ES checks\(^\text{13}\) the project site to see if it is located in drought or flood risk area and if the site is in an urban area. If the site is in a certain risk area, for example, in a drought area, the drought tolerance factor would be multiplied by 1, 2 or 3 based on the severity of the risk. This weighs the impact of drought tolerance in the final tolerance score. If there is no risk for that the factor would be multiplied by zero. Flood tolerance is the same as moisture use range and its levels are listed as none, low, medium, and high which are respectively represented as values 0-3. The same range is true for drought tolerance and shade tolerance. The Tolerance Score will be calculated using the formula listed below:

\[
\text{Tolerance Score} = \left(\frac{(\text{Impact factor} \times \text{flood tolerance} + \text{Impact factor} \times \text{drought tolerance} + \text{Impact factor} \times \text{shade tolerance})}{27}\right) \times 100
\]

**Values and ranges**

*Impact factor:* Impact factor is also categorized in 4 levels. The impact factor represents the degrees of importance or the frequency of extreme environmental conditions (drought, flood and shade) in the given site. Here, 0 (for each of the tolerance scores) means that a particular environmental condition is not relevant, while 1, 2, 3 represents low, medium and high importance of that extreme environmental condition.

\(^{13}\) Through connecting the online climate analysis tools mentioned previously.
**Individual Tolerance:** Each of the individual tolerance (drought, flood and shade) range is between 0-3 when 0 represents no tolerance, 1, low tolerance, 2, medium tolerance and 3, high tolerance.

The range for the cumulative tolerance score is between 0-27. The score is divided by 27 (the range) and multiplied by 100 in order to have the final score as percentage.

**Tolerance Score Interpretation**

The application finds flood tolerance, drought tolerance and shade tolerance from the plant database and applies the above formula to achieve a number from 0-100. The range will be classified into three subranges that is illustrative of the performance of the designed planting in regard to tolerance, where 0-30 would be considered as poor tolerance performance, 30-60 shows average tolerance performance and 60-100 represents good tolerance performance.

**Plasticity Score**

As defined in chapter 2, *plasticity* has a close affinity with tolerance and it means how well species' perform across a range of environmental conditions. The difference between tolerance score and plasticity score is that that tolerance score shows how tolerant a species is under certain environmental condition or series of environmental conditions, whereas, plasticity reflects the number of environmental conditions in which the species can survive. The higher the number the more resilient is t the species. The Plasticity Score will be calculated with the formula provided below:

\[
\text{Plasticity Score} = \frac{((\text{Temperature Plasticity} + \text{Light Plasticity} + \text{Soil Type Plasticity} + \text{Soil Moisture}) - 4)}{18} \times 100
\]

**Values and ranges**

*Temperature Plasticity:* The hardiness zones range between 1-13. Temperature plasticity is defined as the number of hardiness zones in which the plant survives. So Temperature plasticity has the same range of 1-13.
**Light (Solar) Plasticity:** Three light conditions are defined; Sun, Partial Shade and Shade. Light plasticity is defined as the number of the light conditions in which the plant can survive. Therefore, the range for Light (Solar) Plasticity is between 1-3.

**Soil Type Plasticity:** Three soil types are defined; clay, loam and sand. Soil type plasticity is defined as the number of the soil type conditions in which the plant can survive. Therefore, the range for the Soil Type Plasticity is between 1-3.

**Soil Moisture:** Three soil moisture types are defined; dry, moist and wet. Soil moisture plasticity is defined as the number of the soil moisture conditions in which the plant can survive. Therefore, the range for the Soil Moisture Plasticity is between 1-3.

**Plasticity Score Interpretation**

The application calculates temperature, light, soil type and soil moisture plasticity scores from the raw data in USDA plant database and applies the above formula to achieve a number from 0-100. The range will be classified into three subranges that is an indicator of the performance of the designed planting in regard to Plasticity, where 0-30 would be considered as poor Plasticity performance, 30-60 shows average Plasticity performance and 60-100 represents good Plasticity performance.

**(Bloom) Redundancy Score**

As defined in Chapter 2, redundancy is another essential criterion for designing resilient urban planting. Functional redundancy can be achieved through having different species with overlapping ecosystem services such as blooming (nectar producing), which is crucial for pollinators. Although there are many other ecosystem services that can be addressed, the prototyped expert system in this thesis only calculates the Bloom Redundancy score. Bloom redundancy is important since the designed planting scheme will able be to provide the same ecosystem service (in this case nectars for pollinators) if one or some of the plants will fail under extreme environmental conditions. Here the Bloom Redundancy Score is:

**Bloom Redundancy**= \( \text{Number of Species in bloom in each month} = \sum_{n=1}^{12} n \)
Values and ranges

Unlike Tolerance and Plasticity scores, there is no specific range for optimum redundancy. Here, our focus is to encourage redundancy in general, which means having more than one species with the same ecosystem service (providing nectars for pollinators) at each point in time.

Redundancy Score Calculation Algorithm

The application checks the bloom period of each species and identifies number of the plants that are in bloom a certain month. If the number is 0 or 1, it suggests to the user to raise the bloom redundancy. The recommended redundancy is 3 (having three species in bloom at each point in pollinators season) where the system would have a good margin of redundancy.

Pre and Post Design Evaluation Flowchart

The expert system flowchart including both pre-design and post-design evaluations steps and sequences is shown in Figure 18.

In addition to calculating resiliency-related scores, other data visualizations can be done to help the users/designers understand the planting scheme through time. This includes showing the color palette of a planting scheme throughout a year or in longer periods of time. As a sample of such data visualization and also as part of a rule-based resilient design expert system, I have developed an application in Processing programming language. This application shows how we can effectively use data and rules for developing an expert system which is important in terms of actual implementation of these ideas into a working application. The research related to development of this application is published in DLA journal and the paper is attached as appendix I.
Figure 17: Flowchart of the ES resiliency score calculation
Scenarios of Use

This section of chapter 4 situates the prototyped application in actual contexts and explains how it can be used and demonstrates its utility. This section also explains how this application can result in more resilient urban landscapes. Although the detailed evaluation of the application will ultimately require testing with groups of participants or in later phases deployed as an actual pilot study within a neighborhood, at the end of this section, I explore the ways in which widespread use of the application can result in creating more resilient urban landscapes.

As mentioned previously, the tool is intended for use in several urban areas around the world that face different environmental and social challenges due to climate change. However, in order to have a clearer understanding of the application, I narrate the stories of use in context of the city of Philadelphia. This city was chosen due its current strong programs and initiatives to encourage citizen for initiating green projects specifically related to green infrastructure and stormwater management.

The primary users of the application are citizens. However, designers (landscape architects, urban designers among others), people working for NGOs and governmental organizations can also substantially benefit from the application. Although the four stories below are about citizens using the app, it also demonstrates how NGOs or governmental organizations can serve as vehicles for introducing the app to the citizens. NGO's and governmental organization can also benefit directly from using the app or receiving data and analyses about the neighborhoods.

Philadelphia

The City of Philadelphia has specific potentials and issues that makes it relevant to this research. Philadelphia experiences several challenges due to a population decrease in the recent decades such as increase in number of vacant properties in the city. Philadelphia, like many other metropolitan areas, will be affected by extreme environmental events resulting from climate change such as flood and sea level rise\(^{14}\). At the same time, there are robust governmental and non-governmental initiatives to make the city more sustainable. In terms of stormwater

\(^{14}\) Look at http://toolkit.climate.gov/climate-explorer/ for seeing the environmental risks in the city
management, The Water Department\textsuperscript{15} helped to set stormwater fees which is calculated for each property based on its amount of impervious surfaces. The department also provides exemption for citizens that adopt a stormwater best management practices (BMP) (such as rain gardens, rain barrels, green roof, etc.). Despite these initiatives there are challenges to get people involved in these programs.

According to Crisostomo et al. (2014), a main barrier to public participation in any green infrastructure incentive program is the inconvenience of hiring experts for any part of the process. This would present “both an administrative and financial burden on the potential applicant” (Crisostomo et al. 2014, p.21). It is within this context that the tools such as our prototyped application can play a role in facilitating behavior change, increasing awareness and knowledge and making the expert knowledge more accessible to local citizens.

Four scenarios or stories of use below illustrates why and how citizens can use “our app” in Philadelphia.

**Stories of Use in Philadelphia**

**Story 1: Jeff, a property owner**

Jeff (Figure 19) lives in Philadelphia.

As an owner of a property with an area of 19,614 ft\textsuperscript{2} and impervious area of 17,553 ft\textsuperscript{2}, he paid $200 in stormwater fees last year.

He is unhappy with the appearance of his yard and also wants to reduce his stormwater fee through creating a rain garden in his backyard. On one hand, he cannot afford to hire an experts/designer and in the other hand, getting help from the water department requires going through a lengthy and complicated procedure.

One day he sees an ad in his neighborhood’s community park that a NGO helps community members to create their own rain gardens and rain barrels. He meets the people from the NGO

\textsuperscript{15} For more information on the initiatives look at: http://www.phillywatersheds.org/
and they introduce “Our App” which helps citizens to create resilient landscapes and provides a platform to access essential knowledge and materials that already exists in the community.

He downloads the app and he finds out that one of his neighbors is already using the app. He pairs with him and starts to design a rain garden.

**Story 2: Peter, a garden lover**

Peter (Figure 20) is a retired chemical engineer and he loves gardening. He is interested in the water department initiatives for expanding green infrastructure in the city and appreciates their efforts for building green infrastructure in the city.

Philadelphia water department chapter of green stormwater infrastructure wants to encourage people to adopt Best Management Practices (BMP) such as creating rain gardens.

The department provides some online tools to citizens, including impervious area calculation and virtual installation of Stormwater Management Practices (Stormwater Credits Explorer). The latter tool is only for non-residential buildings and requires expert knowledge to use it. He thinks that it would be great idea if he can use his fellow community members experience rather than a mere analysis tool to start a new garden.

In order to connect to more people and reach a more resilient design, the Water Department decides to provide the link to “our app” and encourages residents to use the app for a pilot project in Peter’s neighborhood.

Peter sees the link in the website. He thinks that this application is more in tune with his idea of gardening than other tools. The application can also help him to learn more about resilient design. He downloads the app and starts using it.

**Story 3: Mary, an environmental activist**

Mary (Figure 21) is a community environmental activist.

She is eager to improve environmental conditions of her neighborhood but she is tired of the time-consuming process of bringing experts and people together. She also thinks that the community meetings are not that inclusive and many young citizens in the neighborhood do not attend those meetings.
One day in a native plant festival in the neighborhood, she sees an ad about “our app”. She thinks that this app can be helpful to engage young people and also make expert knowledge more accessible. She also likes the way in which the application can connect people in the neighborhood.

She downloads the application and shares it with some of her friends in her next meetings with people in the community.

**Story 4: Emily, a volunteer student**

Emily (Figure 22) is a student at Temple University. She lives in the Lower North district within walking distance of the campus. She loves local food and urban farming. She also wants to find volunteer opportunities in the neighborhood.

She finds out that there is no community garden close to where she lives. She is passionate about volunteering in one in summer to grow some food and help elderly people in the community to engage in a social activity. However, she does not know how she can start a community garden project in the neighborhood.

She sees an ad in a board in her college and thinks that she will try to see if she can start a community garden project through this app. She downloads the app and initiates a project in the neighborhood and makes it open to design and evaluation. Some folks join her project and they connect to each other. As the community around the project grows, they will talk with the municipal officials to discuss the possibility of starting a community garden at a lot that they have chosen.
Proof of Concept: How can the wide-spread use of the online platform can result in more resilient urban landscape?

As mentioned in chapter 2, resilience is defined as the ability of a system to absorb changes, self-organize and increase its capacity for learning and adaptation (Cumming 2011). Although there is not any precise evaluation method to measure these characteristics in complex urban systems, here, I argue how using this online platform can improve each of these characteristics in an urban context. As it is emphasized in chapter 2, it is important to see urban landscape as coupled human-nature systems and consider both social and environmental aspects of resilient design. In order to see urban systems through the lens of complexity thinking, it is also important to pay attention to different nested scales.
The expert system in the proposed online platform provides clues for the users on the climate change risks they may face and how they can design resilient urban planting that follows ecological resiliency rules such as plasticity and redundancy. The very definitions of plasticity and redundancy have close affinity with resilient system characteristics such as absorbing changes, self-organization and capacity for adaptation. High plasticity planting schemes will survive in multiple environmental conditions, therefore they can easily absorb change from one condition to another. They also can self-organize or adapt to new environmental condition due to their intrinsic high adaptability. Redundancy also plays an important role in self-organization and increasing capacity for adaptation. Redundancy means having multiple species with the same ecosystem service. In case of a severe environmental condition, redundant planting systems have a higher probability of maintaining their ecological function since if one species fails, other species will be available for providing the same ecosystem service. In this sense, redundant systems' self-organize in a new environmental condition.

The expert system component of the online platform developed provides resiliency strategies for design in a specific lot. However, it is necessary to emphasize that resilient urban systems will not result from a few scattered resilient green spaces. The idea of this online platform is to increase these kinds of initiatives that can then result in dramatic change in the resiliency of whole urban systems. For example, the important aspect can be to connect these small green spaces to existing large green patches and corridors within a city. The collective result of the small resilient spaces can also result in considerable reduction in impervious surfaces, stormwater reduction and food production increase in the scale of the neighborhood and then the city. The importance of the collective result (based on social components) is the main reason that this research is not solely focused on ecological resilient design and emphasizes developing and shaping a resilient social structure for achieving wide-spread environmental resiliency at different scales.
Resilient Society Shaping Resilient Environment: Absorbing changes, Self-organization, Capacity for learning and Adaption

It is not possible to completely design resilient urban landscapes using top-down design approaches of urban parks. A considerable quantity and quality of urban landscapes is shaped by people in their private properties or small community gardens and green spaces. Citizens are also the main force that respond to the aftermath of a natural disaster and are the force behind rebuilding efforts or adapting to new conditions. Although organized top-down disaster management is necessary, self-regulated distributed responses to post-disaster situations has proved to be very effective (Brugh et al. 2015).

Using the online platform, people can help to shape resilient infrastructure both in pre and post disaster situations. Designing a framework for co-creation, engagement and knowledge transfer is crucial for both pre and post-disaster planning. Here, the online application provides a platform for collectively expanding the amount (quantity) of resilient landscapes and improve community members’ capacity for learning. If a change happens, the social system would be in a position to absorb change easily using the established framework of distributed but connected engagement. The platform connects individuals with other people and help them share their experience in the adaptation process. Here, knowledge can transfer across urban scales form an alley to a neighborhood to the whole city.
Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Method and Process

Chapter 4: Discussion

Chapter 5: Conclusion
Chapter 5: Conclusion

Summary

In the context of uncertainty resulting from climate change, more frequent severe environmental events are expected. In many cases, urban communities are not prepared to face these challenges and our built environment is vulnerable in this regard. Resilience is a timely concept that defines the preparedness of our urban systems to withstand these abrupt changes. The concept has received much attention in urban and landscape design but there is a gap in the literature that links large-scale resilience strategies to site-scale resilient design.

Resilience is also a character of complex adaptive systems and in order to design resilient landscapes, we need to see landscape as coupled human-nature systems and actively engage them with its dynamic bottom-up social and ecological processes. However, current traditional approaches and tools in the landscape architecture discipline do not have the capacity for incorporating these processes into design at the site scale. The discipline also mostly uses CAD for static representation of the landscape and most of the available digital tools do not allow for easily incorporating the dynamic nature of landscapes in the design process. Meanwhile utilizing the potentials of socio-computational systems for more dynamic design solutions are also relatively unexplored in landscape architecture.

It is in this context that this thesis provides a framework for Information Technology (IT)-assisted participatory urban landscape design with the focus on shaping resilient landscapes. This framework integrates theories of collective intelligence systems, social physics and participatory urban planning and design to develop a platform for participation. Focusing on urban planting, this framework also benefits from rule-based approaches in ecological design to propose an expert system that can evaluate the resiliency of a designed landscape. An online co-design tool is prototyped as an example of this framework. The thesis argues that the widespread use of the application can improve ecological and social self-organization and increase the capacity for adaption in urban communities; the characteristics that define a resilient system.
Future Research

An important immediate next step for this research is to turn the developed prototypes of this co-design tool to a version that can be introduced to groups of participants for evaluating the structure and the interface of the app. The first evaluation can be a scenario-based game-like lab experiment. The prototype then can be refined based on the participants' feedbacks and evaluation. The second step would be to turn the prototype to a first working application and test it through a pilot study in an urban community. This requires identifying and analyzing a starting location in which the app can be beneficial to the community for shaping resilient landscapes. There is also a need to identify the best platform(s) for operating the app and creating a plan that overviews the short-term, mid-term and long-term app development process.

In a larger context, beyond the prototyped app, this research creates and expands the approach that has been developed for the use of collective intelligence systems in the urban design process. This can be possible with more in depth analysis of the literature in CIS and the urban design process. Through synthesizing the CIS experiences and approaches in information science and technology and the urban design process, a new comprehensive approach can be developed for IT assisted participatory urban design.

The research also can be extended to develop a more comprehensive resilient landscape design expert system. While the focus of this expert system was on urban planting, other properties of landscape such as material design, hydrology or even placement of social activities can be added to the evaluation of resilient landscape design solutions. Series of relevant criteria such as durability and maintenance (for material design), alignment with the natural patterns of water flow and flexibility for change (for hydrology), alignment to the needs of users and flexibility (placement of social activity) can be added and quantified in order to evaluate the resiliency of a designed landscape system.
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Appendix A

Reflecting Time in Computer-aided Landscape Analysis and Design:
Developing an Application for Modelling Seasonality and Resiliency in Small Scale Landscapes

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Abstract: Time is a vital factor to any landscape design. Landscape design solutions “rely on transformation, growth, decay, flow, and settlement to produce evolving solutions” (Walliss et al. 2014). Although there have been advances in large-scale scenario modelling and analysis, the evolving nature of landscapes are hardly reflected in the way landscape architecture uses CAD in small-scale designs.

The timely attention of the discipline to urban resiliency accentuates the importance of acknowledging dynamics of landscape systems in design process. Plants, as living matter of designed landscapes, change through time and are affected by seasons and extreme environmental conditions. Although there are local nuances to the parameters that can affect a planting scheme through time, many aspects of it can be parameterized. In this regard, I developed an application in Processing programming language that addresses the influence of time-related factors such as seasonality and environmental changes on planting design. Accessible large databases such as USDA plant database and the literature in ecological rules for urban planting resiliency (Hunter 2011) are incorporated into this rule-based CAD tool for designing resilient landscapes.

This paper provides a brief review of landscape resilience and the current use of CAD in small-scale landscape design. In addition, it explains the underlying rule-based ecological theory in the process of the application development. Lastly, it demonstrates the application developed as an example of this parametric approach to landscape design. The interactive app shows the resiliency of a planting scheme under different extreme environmental scenarios, bloom resiliency, and the colour palette of the planting scheme throughout a year. This parametric tool has both design and educational purposes and is applicable in design analysis, facilitating user-engagement, and long-term maintenance and monitoring of small-scale landscapes.

Keywords: Time, Data Visualization, Processing, Resilience, Urban Landscape, Landscape Apps

1 Introduction

This paper is part of an on-going research agenda on use of information technology and CAD tools for designing resilient urban landscapes. While the broader research explores both social and environmental aspects of landscape resiliency in multiple scales, here, the paper focuses on resilient planting design in small-scale landscapes and provides an example of simulating resiliency in a planting scheme. The length of this paper does not allow for in-depth discussion of landscape resilience or the use of CAD in landscape architecture. However, a brief review on these two subjects has been included to draw a theoretical foundation for the application development. Another essential theoretical base is research on resilient urban planting (Hunter 2011). Here, the criteria mentioned for response and functional diversity in planting design are incorporated into the application design.

The application is written in Processing programming language. Processing is a Java-based language with the focus on new media and digital arts (Bohnacker 2012, Shiffman 2012). The databases used for the sample experiment include USDA plant data and the plant data provided in Hunter (2011). The application shows the changing landscapes through focusing on the factors that influence the plants long-term endurance in general and the ecosystem service they provide for pollinators in particular. In this regard, I have focused on the change in the plants through different seasons/months of the year and severe environmental conditions.
2 Landscape Resilience, Time and CAD Tools

2.1 Landscape Resilience: Matter of Scale and Time

The concept of resilience has received much attention in urban planning and design in the recent years. This attention specifically revolves around cities (Wallace and Wallace 2008, Wu and Wu 2013). It is believed that the shocks that today’s cities may face are different from those in the past in terms of their scale and pace due to globalization and climate change. Rapid depletion of natural resources and the increasing frequency of extreme ecological events have been mentioned among the factors that make resilience a timely focus (Eraydın & Taşan-Kok 2013).

Resiliency is a term introduced by Holling (1973) in the context of ecological science. In his article “Resilience and Stability of Ecological Systems”, he emphasizes the importance of focusing on change rather than constancy and qualitative features rather than quantitative ones in studying systems; in particular, ecological systems. Since then the term has been expanded in terms of both its notion and application in many studies that address social-ecological systems.

Since different disciplines have touched on the idea of resilience in their specific contexts, there are many different definitions of the concept. Cumming (2011) provides two definitions of resilience. The first one defines resilience as the ability of a system to absorb changes, self-organize and increase its capacity for learning and adaptation. The second definition is based on system identity. Here, resilience is defined “by quantifying identity and assessing the potential for changes in identity” (Cumming 2011, 13).

Focusing on change is the shared part of many definitions of resilience. Resiliency measures how a designed system responds to gradual or abrupt changes such as a hazardous events (Field et al. 2012). Change is defined within the factor of time and we can analyse the resiliency of a landscape through studying its change during a year or under severe environmental conditions (specific moments in time).

Although there are several studies on landscape resilience, the link is missing to connect these studies to design decisions at small scales. In order to see different components, relationships, processes and feedbacks necessary for assessing resiliency of a landscape system, landscape architects should pay attention to the different nested scales. Many of the research studies on landscape resilience, though, only reflect upon the large scales (which is definitely necessary) and rarely address the local interactions (Cumming 2011). This occurs because many landscape architecture projects happen at small-scale and practitioners in different levels of construction industry become more and more interested in incorporating the idea of resilience into their design (ASLA 2014).

2.2 CAD for a Dynamic Design

Here, the gap is the lack of principles and tools for designing resilient landscapes at small scales. Our design approach in small-scale landscapes focuses more on static scenes, even when we consider factors that are more dynamic. This is mainly because design is considered as the embodiment of the ideas and analyses in a fixed form, while the reality of landscapes are much dynamic and evolving.

Another contributing factor to inability of the landscape architects to reflect the changing nature of the landscape in the design process is the way that the discipline uses CAD. Computer-aided design started in architecture and caused a major paradigm shift in the way it is conceived and represented (Varouli 2011). Early in the history of computer-aided design, Yona Friedman emphasized how CAD can produce a “repertoire of possibilities” for the users to choose and allow them to see and correct the design errors. Errors can be determined based on quantitative rules in the context of design; e.g. size of the structure in an architectural design project. According to Friedman, the main potentials of CAD lie in its educative and adaptive nature and its ability to produce different design alternatives in a transparent process based on certain design rules (Varouli 2011). This rule-based participatory approach to CAD was faded away in mainstream design for years and it has come back strongly in recent decades as the idea of generative or parametric design.

Parametric design takes place through defining constrains/parameters of design and their relationship/dependency. Parametric tools are interactive; users can change the value of parameters (Bier 2013, Steino et al. 2013). They can instantly visualize the change in the system and thus provide a high level of detail even in early stages of design. In the context of parametric tools, the designer will actually be able to design the
rules rather than the object of design. From the simple rules, complex configurations can emerge and time-related parameters of design can help to trace the design through time.

Parametrics has been explored vastly in architecture, urban design and planning fields. Landscape architecture has been slow to embrace new technologies to expand design processes and techniques (WALLISS et al. 2014), and parametric design is not an exception. The discipline’s use of parametric design has been influenced by the conceptualization and application of the parametrics in architecture, which is more focused on finding optimized forms. This happens because “landscape design solutions rely on transformation, growth, decay, flow, and settlement to produce evolving solutions” (WALLISS et al. 2014). The need for a distinctive approach for the use of parametric design in landscape architecture is apparent considering the differences between the two fields. The changing aspects of the landscapes require a more dynamic use of parametric design.

This paper focuses on planting as one dynamic aspect of landscape design. This aspect has been chosen for two additional reasons. First it can be easily parameterized and second, the large datasets showing the characteristics of many different plants are available online.

3 Design with Data: An Experiment of Planting Design with Processing

3.1 Urban Planting: Resiliency under climate change

Plants, as the living matter of designed landscapes, change regularly through the seasons. They also are affected by warmer average temperatures and extreme environmental conditions due to climate change. Although there are local nuances in their change or growth pattern through time, general rules exist that can help us to achieve a general understanding of the resiliency of the planting schemes.

There is a line of research that calls for adaptation strategies to buffer ecosystems against uncertainty resulting from climate change. Many adaptation strategies are concentrated on urban planning solutions for “sea-level rise, heat island effects, health impacts, and water treatment”, while strategies for urban planting are limited (HUNTER 2011, 174). Hunter (2011) provides a rule-based approach to urban planting resiliency through rating the plant species based on ecological criteria for plasticity, functional redundancy, response diversity, and structural diversity. Ecological resilience is defined as the ability of maintaining ecosystem function under environmental disturbance and depends on both functional redundancy and response diversity. While functional diversity is defined as “the number of species contributing to an ecosystem function”, response diversity deals with “the range of reaction to environmental change among species contributing to the same ecosystem function” (ELMQVIST et al. 2003, HUNTER 2011, 174).

As an example, Hunter (2011) points to a planting design with the goal of support for generalist pollinators. Here, functional redundancy can be achieved through having overlapping bloom times. For response diversity, the overall species that provide nectar should be flexible to the environmental variations such as both drought and flood events (HUNTER 2011, 175). The rule-based approach of Hunter (2011) adaptation strategies and the availability of large plant databases helped my experiment of parametric urban planting design with Processing programing language.

3.2 Visualizing Resilience in Processing

Focusing on the Hunter (2011) example of designing a garden with the goal of support for generalist pollinators, I created a sample planting scheme in Processing. Based on the discussed criteria of response diversity, we need to know in which month we will have the species in bloom and if there is enough overlap in bloom time. Changing the colour pallet of the planting scheme due to the species’ different bloom times and colours is also important in terms of the aesthetic design decisions. Here, we’re not limited by a fixed scene and can design the landscape with its changing nature. The response diversity of the planting scheme also depends on its functionality under
severe environmental conditions. Three extreme conditions are considered: flood, drought, and extreme heat event.

Input Data

The application reads two CSV files. The first CSV file has the information for the plants’ locations (the centre x and y), maximum size (diameter) and their associated ID. The sample planting scheme include trees and bushes. This file can be easily exported from an AutoCAD file of a designed planting scheme. Each ID is associated with a specific plant species that connects the first CSV file to the second. The second CSV file has all necessary information on the characteristics of the plants including bloom time, bloom colour, drought resistance, flood resistance and associated temperature hardiness. The base for second CSV file is retrieved from USDA Plant database (http://plants.usda.gov/). The related tags on the USDA plant database include flower colour, bloom period, drought tolerance, and moisture use. The associated hardiness zones and the exact bloom start and end month have been added from Hunter (2011) paper for this specific sample of the plant data. The bloom colours have been translated to hex keys. The bloom start and end months range from 1-12 represent the months of the year. The hardiness zones are listed from 1-9. The number of the hardiness zone in which the plant can survive represents its tolerance to temperature variation and is labelled as heat tolerance. The heat tolerance is added to the USDA plant database and is represented with the range of 0-3 where 0 represents no tolerance and 3 represents maximum tolerance. Drought tolerances are listed as none, low, medium, high which are respectively represented as values 0-3. The same range is used for moisture use.

Algorithm

The code checks the first CSV file and draws the plants relatively on the screen based on each plant centre location and maximum size (diameter). Then it searches on the second CSV file for the related characteristics for each ID. Based on the user input in the slider for different months of the year, each plant colour might turn to green (have leaves without bloom), grey (without leaves) and particular colour (the bloom colour when it is in bloom). When any of the extreme environmental conditions button is pressed the application checks for each plant tolerance to the related extreme event such as heat tolerance, flood tolerance and drought tolerance. If the value is 0 (no tolerance), the colour will change to black to represent the plants that may fail under that environmental condition.

Fig. 1: The application shows the species in January. The slider can be changed to see bloom time and colour in different months of the year.
Fig. 2: The application shows the species in bloom in July. Bloom colours are shown based on the hex keys associated for each plant ID.

Fig. 3: Three buttons designed for severe environmental conditions. Here, the black circles shows the species that will fail under an extreme heat event.

4 Discussion

The newer revision on the application also provides the number of species in bloom for each month and shows if there is both flood tolerant and drought tolerant species in bloom in each single point during pollinators’ season. Although there are some limitations in using the application, it provides a dynamic platform for early design decisions. The main two important contributions of the application are in:

1) Providing an example of linking rule-based ecological design strategies to existing data for small-scale landscapes.

2) Incorporating the idea of resiliency to the early stages of design instead of seeing it as an ad-hoc strategy. The limitation of this application is on linking the designed planting schemes with the data. Although exporting a CSV file for each planting design layer can easily be done in the existing CAD platforms such as AutoCAD and Rhino, for each change a new CSV file should be produced and be imported to the application code. While Processing provides a helpful platform for data visualization, the newer instances of this application can be designed as a plug-in for an existing CAD software such as Rhino. In doing so, the application can be integrated to the place where many possible users (landscape architects and students) design. The algorithm also can be turned into an online platform developed with HTML5 with the options for the real-time interactive design. In doing so, the application targets its user not only from design experts but also it provides insights for lay-users on how to design resilient small urban gardens. In this regard, the app can be considered as an expert system for facilitating public participation in resilient landscape design. The next step in the development of this application is to prototype different aforementioned platforms (software plug-in or web application) and try it with actual users for further evaluation on its function and user experience design.

Another challenge is that the USDA database does not provide all the necessary information. Although it is easy to add some of the needed factors to the database for small designs, it is important to find a long-term solution
for gradual development of a plant database with all the necessary information for design/analysis. A more detailed database that has, for example, the annual average growth for each species also helps to simulate other time-related factors such as growth pattern in time. The growth pattern can consider other spatial factors such as plant initial size and plant spacing. Here, a more detailed database allows for analysing direct relationships between the planting scheme’s spatial configuration (including plant volume and spacing) and its resiliency under different environmental stressors.

5 Conclusion and Outlook

Time has been always an important factor for landscape design in any scale and is an indispensable part of landscape resilience analysis. However, the lack of approaches and tools for incorporating the dynamics of resilient landscapes in small-scale design, in many cases, results in designs that are the static renderings of fixed scenes. In the context of ever-increasing attention to resilient landscapes and access to big databases, this paper argues that the border between data visualization and design should be blurred. Data visualization as one approach to parametric design can fill the gap between the rule-based approaches to ecological landscape design and specific design decisions at site scale. Although the quality of visualization outcomes is always dependent on the quality and quantity of data and the extent to which our resiliency rules are comprehensive, they provide a base for exploring the dynamicity of landscape through time.

References


Appendix B: Online Climate Analysis tools

This appendix provides a brief introduction to three online climate analysis tools of Climate Change Scenarios, Climate Explorer and Cities Impacts & Adaptation Tool.

Climate Change Scenarios

“The Climate Inspector (Figure 20) is an interactive web application which expands GIS mapping and graphing capabilities to visualize possible temperature and precipitation changes throughout the 21st century. The maps and graphs are generated from a large dataset of climate simulations by the NCAR Community Climate System Model (CCSM4). These simulations were prepared for the 5th Assessment Report of the Intergovernmental Panel on Climate Change. With Climate Inspector you can explore how temperature and precipitation may change based on different emission trajectories (i.e., Representative Concentration Pathways), investigate climate changes around the globe and through time, inspect climate trends, variability and uncertainty, and download maps and data. Here you can download temporal climate data for a single grid cell” (Climate Change scenario website¹⁶, no date).

¹⁶ https://gisclimatechange.ucar.edu/inspector

Figure 20: Climate Change Scenarios homepage
Climate Explorer

“Climate Explorer (Figure 21) is a research application built to support the U.S. Climate Resilience Toolkit. The tool offers interactive visualizations for exploring maps and data related to the toolkit's Taking Action case studies.

Base maps (imagery, street maps) come from ESRI Web services. Map layers in the tool represent geographic information available through climate.data.gov. Each layer's source and metadata can be accessed through its information icon.

Climate Explorer graphs available via the tools Historical Data tab display 1981-2010 U.S. Climate Normals for temperature and precipitation, overlain with daily observations from the Global Historical Climatology Network-Daily (GHCN-D) database. GHCN-D data have been checked for obvious inaccuracies, but they have not been adjusted to account for the influences of historical changes in instrumentation and observing practices. GHCN-D data are useful for comparing weather and climate, but for long-term climate change analyses, we recommend the National Climatic Data Center's Climate at a Glance” (Climate Explorer website17, no date).
Cities Impacts & Adaptation Tool

“The Cities Impacts & Adaptation Tool (CIAT) (Figure 22) is a climate adaptation planning support tool for decision makers at the city level in the Great Lakes Region of North America. It provides usable data such as demographics, socioeconomic data, and both current and projected climate trends. Using this information, the tool also identifies a custom network of climate peers whose current climate reflects how yours may look in the future. The CIAT also provides a searchable database of adaptation strategies pulled from existing climate action plans from across the country” (Cities Impacts & Adaptation Tool18, no date)

Figure 22: Climate Impacts and Adaptation Tool

18 http://graham-maps.miserver.it.umich.edu/ciat/