Co-Generative:

A Generative Design Paradigm for Fostering Regenerative Communities

Samah Kamalmaz
OCAD University, 2022

Co-Generative:

A Generative Design Paradigm for Fostering Regenerative Communities

By Samah Kamalmaz

Submitted to OCAD University in partial fulfillment of the requirements for the degree of Master of Design in Strategic Foresight & Innovation

Toronto, Ontario, Canada

December 2022

Copyright

Declaration

I hereby declare that I am the sole author of this major research project (MRP). This is a true copy of the MRP, including any required final revisions, as accepted by our examiners.

I authorize OCAD University to lend this MRP to other institutions or individuals for the purpose of scholarly research. I understand that my MRP may be made electronically available to the public.

I further authorize OCAD University to reproduce my MRP by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Abstract

Holistic sustainability literature argues that many of the most serious problems we face today are a result of innovation that is disconnected from its local ecological context. One of the innovations being explored to address the challenges of designing complex built environments is ***generative design***; a collaborative design process that augments human design capabilities with computational power to explore a multitude of design alternatives. ***Regenerative design*** is a holistic design approach that builds on understanding ecosystem patterns that regenerate a system's health and vitality.

In this Major Research Project, I explore the bridge between ***generative design*** and ***regenerative design*** to propose a computationally-augmented design approach that contributes to fostering the health of the system as a whole. Using a strategic foresight framework, I deconstruct the current computational generative design paradigm and construct one that is based on a metaphor of perpetuity and a worldview that values collective flourishing, abundance, and appropriate participation. Building on this new paradigm, I propose a revised generative design workflow that emphasizes collaboration, connectedness with the land, participatory foresight, and emergence. I conclude that a ***regenerative*** generative design approach is community, context, and complexity-sensitive.

Acknowledgements

Greg Van Alstyne, thank you for your generous and ongoing guidance and support of my work on this Major Research Project as my principal advisor. You have challenged, inspired, and guided me in exploring regenerative design and what it means to design with respect for the people and the land.

Dr. Sara Diamond, thank you for helping me refine this report, and for your invaluable guidance and support throughout my internship with the iCity 2.0 team. Bringing together such a diverse team is an art and I hope to have learned some of it from you.

Rhys Goldstein, thank you for reading and sharing your thoughts and feedback on this report, for guiding me through my first generative design project, and for insightfully guiding our team towards the most feasible generative design strategy.

Jeremy Bowes, the opportunity to work with and learn from you during my internship with the iCity 2.0 was a great pleasure. Thank you for most generously guiding and supporting my work in the SFI program and during my internship.

SFI professors and cohort, thank you for making learning and collaboration fun and enriching under the most remote circumstances.

iCity 2.0 Team

My internship with the iCity 2.0 team was a great opportunity to learn about generative design in urban planning. The generative design project presented in Part 2 is the result of the collaborative effort of this team.

Project designers: Samah Kamalmaz, Grace Yuan, Sri Sahiti Vemavarapu.

Project Supervisors: Dr. Sara Diamond, Rhys Goldstein.

Project advisors: Jacky Bibliowicz, Jeremy Bowes, Dr. Matthew Roorda, Greg Van Alstyne, Sara Wagner, Robert Wright.

Project client: The Daniels Corporation.

Scenario Co-Creators

The scenarios presented in Part 5 were created through a series of participatory foresight workshops with co-creators:

Jacky Bibliowicz, Jeremy Bowes, Dr. Sara Diamond, Manal Dimachk, Iris Elliott, Rhys Goldstein, Ellen Hlozan, David Kossowsky, Wafa Osta, Dr. Matthew Roorda, Shireen Salti, Sri Sahiti Vemavarapu, Rania Younes, Grace Yuan, and other anonymous collaborators.

It was wonderful facilitating these sessions and working with everyone.

To my dear family and partner, words cannot begin to express my gratitude for your presence with me through the ups and downs of this journey.

Mom and Dad, your boundless love is behind everything I did and could accomplish. My dear siblings, nieces, and nephews, I am truly lucky to have you with me. Sana, I would not have been able to finish this degree without your support.

Zaid, your presence and your encouragement has always cheered and uplifted me throughout this journey. Thank you for always being there when I needed an SFI colleague, a friend, and a partner to talk to.

I could not have asked for a better support team.

Land Acknowledgement

This learning journey has started and continues from the traditional territory of many nations including the Mississaugas of the Credit, the Anishnabeg, the Chippewa, the Haudenosaunee and the Wendat peoples.

I offer my gratitude to the First Nations for their care for earth and the land on which our communities, neighbourhoods, and cities are able to exist and flourish.

Table of Contents

List of Figures

List of Tables

Executive Summary

In the face of the growing complexity of the problems we face today, the increasing power of digital technology seems to hold the keys we seek. However, based on holistic design approaches such as *regenerative design*, these problems are largely a result of innovation that has evolved beyond the constraints of its immediate ecological context. The literature argues that for design to support ecosystem health, it must be integrated into the regeneration process of that ecosystem.

One of the innovations being explored to address the challenges of designing complex built environments is *generative design*; a collaborative process between human designers and computers where designers define objectives while computers produce, evaluate, and evolve solutions. Utilizing artificial intelligence enables the exploration of a large number of design alternatives, generation of novel solutions, and optimization of solutions to meet multiple objectives.

Generative design has a great potential in supporting the design of ecologically-conscious built environments. To establish a generative design approach informed by regenerative design literature, generative design must be integrated into the local context. This major research project explores how generative design can be developed and implemented in a way that respects the boundaries, resources, and needs of the immediate ecological context to achieve ecosystem health.

The attempt at synthesizing *generative design*, which is computational and dependent on technology, with *regenerative design*, which is qualitative and rooted in the natural world, is admittedly a bold one, as the two approaches seem contradictory. The strength of this research lies in the seeming irreconcilability of the two approaches, as such a synthesis could open up unexplored synergies needed to address complex concerns.

This report is divided into five parts:

Part 1: What are Regenerative Communities?

I start by discussing the concept of *complete communities* and proposing a synthesis of the dimensions of a community's completeness informed by the literature. I discuss the relationship between complete communities and environmentally responsible design, specifically *regenerative design*. I conclude that for communities to be complete, they must be regenerative.

Part 2: What is Generative Design?

I present an overview of how generative design is defined in the literature, and clarify which definition of generative design this project focuses on. I present a real-life project to showcase what a generative design process in an urban planning context looks like. The section concludes with reflections on the promise of generative design.

Part 3: Why Generative Design?

I present a summary of what the literature highlights as advantages of developing and following a generative design process in architectural and urban planning projects. I conclude by discussing three limitations in the conceptualization and process of generative design from complexity and regenerative design perspectives.

Part 4: Generative Design, Where To?

I propose a new paradigm and a revised workflow to address the limitations highlighted in the previous section. Building on this paradigm and incorporating insights from systemic design, generative design, and regenerative design, I propose an adapted generative design workflow to find the bridge between *generative design* and *regenerative design*.

Part 5: The Futures of Neighbourhoods in the Greater Toronto and Hamilton Area

I present a foresight dossier that explores the futures of neighbourhoods and communities informed by a participatory foresight workshop. Three future scenarios were collaboratively generated exploring the futures of neighbourhoods in the Greater Toronto and Hamilton Area. I conclude with a discussion of the contribution of this foresight process to the generative design process.

Co-Generative: From Generative to Regenerative

I summarize key takeaways from this exploration on what makes a generative design process *regenerative*, highlighting the importance of requisite variety, connecting with the physical site, strategic foresight, and appropriate participation in complexity. I then synthesize these elements into three themes that make up what I refer to as a ‘co-generative’ design approach:

- **Community**: the health of a place determines the wellbeing of the people living in that place, and their wellbeing determines how well they can maintain it.
- **Context**: to foster connectedness between people and place, it is hard to substitute direct experience and interaction with the place.
- **Complexity**: regenerative connectedness between people and place is maintained through appropriate participation.

Introduction

“To regain our full humanity, we have to regain our experience of connectedness with the entire web of life.”

(Capra, 1996, p. 296)

Research Question

I feel we might be collectively becoming desensitized as a result of our increasing ecological awareness. While deeply unsettling, the thought of entire populations losing their homes and livelihoods, species ceasing to exist, and ecosystems being destroyed can easily get drowned by our daily concerns and the vicious competition that contemporary economics impose on our attention.

Concurrent with the deterioration of natural ecosystems and our growing distraction are rapid and exponential innovations in information and communications technology (ICT), giving rise to alternative digital environments where more aspects of our lives are taking place. This collective shift towards digital environments has its conveniences, but it also comes with a price. Our presence in the physical world is gradually being replaced by a fragmented presence in digitally-mediated worlds. As we spend increasingly more time in digital environments, **could our knowledge and connectedness with the physical environment be eroding?** If this is true, **how could we care for and hope to restore natural ecosystems at a time when we are losing our connectedness with them?**

This question revolves around the relationship between physical environments and information and communications technology (ICT). When I started this project, the question that demanded an urgent answer seemed to be: h**ow might we design and use ICT so that it provides an enriching addition, not a substitute for, our presence and attention in physical environments?** In other words, **how might we design and use technology to support our connection with the physical world, instead of erode it?**

The issue with this question, however, is that it was based on a false dichotomy between the physical and the digital. The truth is, physical environments are the substrate and ecosystem where ICT can operate. Therefore, technology that leads to the erosion of people's connectedness with the physical world ultimately leads to the erosion of said technology. This is a problem of inappropriate scale-linking, as described by Daniel Wahl. In most of history, human-designed environments and innovations were naturally supported by, and therefore by necessity integrated into, their local ecosystems. Appropriate scale-linking was the basis of historically sustainable innovation (Wahl, 2007). Wahl establishes that the unsustainability crisis we face today is the result of inappropriately scale-linked designs that seem to be independent of their local context, which is made possible by buffers provided by the resilience of the ecosystem, which in turn is gradually eroded by those designs (Wahl, 2007). **What does this say about the scale-linking state of the exponential innovation and technology we have been witnessing in the past few decades?**

I came to the conclusion that the question of technology and its role in environmental sustainability has less to do with how technology can support connectedness with the physical world, and more to do with the place technology takes in the physical world. For technological innovation to have a role in ecosystem regeneration, appropriate scale-linking of any technology within its local context in the physical world must be a primary part of the discussion. **How might we design and use technology with the awareness of the impact that technology has on different scales in the ecosystem?** Given the global scale of corporations developing and offering these technologies, investigating the impact of these technologies on the local scale becomes particularly important. **How might we design and use technology in a way that respects the boundaries and conditions of the local context where that technology is used?** I think exploring these questions can lead to a new paradigm that enables us to design and use technology in a way that supports environmental sustainability.

Sustainability, however, is not sufficient at this point in time. Bill Reed (2007) describes the trajectory of environmentally responsible design from conventional practice being "one step better than breaking the law," to *regenerative design* where humans "participate as nature" leading to the co-evolution of the whole system. On that trajectory, sustainability is neutral as it aims to do no damage, but does not restore the ecosystem (Reed, 2007, p. 676). Sustaining the health and resilience of the ecosystem is what is needed, and these are emergent properties of regenerative cultures as they learn to thrive within the constraints and opportunities provided by their local ecological, social, and cultural conditions (Wahl, 2016). Our focus therefore must go beyond sustainability towards regeneration.

Around the time I was developing my research question, I started a Mitacs internship working on a research project that looked at how *generative design* can be applied in urban planning contexts, specifically in designing complete communities. Generative design has been applied in computer-aided design and manufacturing (CAD/CAM) to generate optimized, performance-driven design solutions for engineering problems. The challenge in applying the same approach to architectural and urban planning problems is due to the complexity of these contexts as a result of the large number of stakeholders and objectives that are often conflicting and difficult to reconcile. In addition, the majority of design objectives in the built environment are qualitative and difficult to translate into algorithms that generative design tools can work with.

Learning about generative design and using some of its tools throughout my internship, I found scoping this project around that same technology to be helpful in adding depth to the discussion. Instead of a broad discussion of ICT applications in the built environment, I have focused my exploration around generative design as one of the technological innovations being introduced to the architectural and urban planning space. While the discussion and outcomes of this project are particularly relevant to generative design, I believe that the conclusions can also be applied to the broader context of ICT. This is because in my discussion, the specific technology of generative design makes up the surface layer, with systemic causes, worldviews, and metaphors underlying that layer and other technological innovations in the same space.

In this project, I explore the question: **How might we establish a regenerative, generative design process for architectural and urban planning projects that facilitates the emergence of whole ecosystem health?** In other words, **what aspects of the current conceptualization and workflow of generative design might we need to rethink for generative design to play a role that goes beyond optimization and extends to support the health of the environments we build?**

How might we establish a *regenerative* generative design process for architectural and urban planning projects that facilitates the emergence of whole ecosystem health?

Methodology

I have followed a mixed methods approach in exploring this research question.

For **Part 1: What are Regenerative Communities?** I reviewed complete community literature and synthesized the findings into nine dimensions of complete communities. I then referred to Bill Reed, Pamela Mang (Reed, 2007; Mang & Reed, 2020;), and Daniel Wahl's (Wahl, 2007; 2016) work on environmentally responsible and regenerative design to build the concept of regenerative communities based on complete communities.

For **Part 2: What is Generative Design?** I reviewed literature on the definitions of generative design and the workflows that recent generative design studies have followed. Working with some generative design tools and using them in a real-life project supplemented and clarified the workflow. The generative design workflow was informed by the design process of Autodesk's office space in Toronto (Nagy et al, 2017a), Autodesk University's conference hall in Las Vegas (Nagy & Villaggi, 2020), and a residential neighbourhood development project in Alkmaar, Netherlands (Nagy et al, 2018).

For **Part 3: Why Generative Design?** I reviewed a number of recent generative design projects and thematically analyzed that work to extract the advantages of a generative design process based on the literature. I then assessed these advantages from a complexity and regenerative design lens, with reference to Dave Snowden's Cynefin framework (Kurtz and Snowden, 2003) and Finger and Portmann's discussion of smart, learning, and cognitive cities (Finger & Portmann, 2016).

For **Part 4: Generative Design, Where To?** I used Sohail Inayatullah's Causal Layered Analysis framework (Inayatullah, 1998) to deconstruct the current generative design paradigm and construct an alternative one. The methodology is discussed in detail under the related section. I then referred to Peter Jones' Systemic Design Principles for Complex Social Systems (Jones, 2014), Christopher Alexander's Generative Codes (Alexander et al, 2005), and Daniel Wahl's work on Designing Regenerative Cultures (Wahl, 2016) to propose a revised generative design workflow.

In **Part 5: The Futures of Neighbourhoods in the Greater Toronto and Hamilton Area**, I present a foresight dossier of future scenarios that were created through a participatory foresight process I facilitated based on Wendy Schultz' Manoa Future's Wheels (Schultz, 2015). The methodology is discussed in detail under that section.

Part 1:

What are Regenerative Communities?

One of the leading concepts shaping urban growth in the Greater Golden Horseshoe Area is the concept of ***complete communities***. Ontario's 2020 growth plan identifies achieving complete communities as the first guiding principle for growth in the province. This section provides an overview of what complete communities are and discusses the relationship between complete communities and environmentally responsible design, particularly ***regenerative design***.

Contents:

Complete Communities

A growing number of cities are working on designing automobiles out and reversing the impact these vehicles have had on their landscape (Peters, 2020; 2022; O'Sullivan, 2022). While cars have certainly revolutionized our mobility, physical inactivity, obesity, death and injury from crashes, cardio-respiratory disease, community severance and climate change are some of the many negative impacts they have had on cities over the past century (Douglas et al., 2011). Automobiles seem to have started a chain reaction that has transformed the urban landscape, and reversing that transformation is not a matter of simply taking cars out of the landscape. The Congress for the New Urbanism, Smart Growth strategies, Transit-Oriented Development, Chrono-Urbanism, are some of the movements that emerged as a response to the interconnected issues our urban landscape is contending with such as suburban sprawl, racial and economic segregation, and the deterioration of natural environments and built heritage.

For example, the Charter of the New Urbanism supports compact, pedestrian-friendly, and mixed-use neighborhoods where street networks encourage walking and reduce the need for automobile use. In such neighbourhoods, activities of daily living can occur within walking distance or accessed easily through transit (Congress for the New Urbanism [CNU], 2015). Smart Growth strategies encompass mixed land use, walkable neighbourhoods, compact buildings, diversity of housing and transportation choices, and stakeholder collaboration and engagement (Duany et al., 2010). Transit Oriented Development (TOD) aims to maximize the development of compact, walkable, pedestrian-friendly, and mixed-use communities around high quality transit systems (Transit Oriented Development Institute, n.d.). Moreno's 15-minute city, Da Silva's 20-minute city, Stockholm's 1-minute city, Vancouver's 5-minute city, Brussel's 10-minute city all ride on the concept of Chrono-Urbanism, which states that residents' life quality in cities is inversely proportional to the amount of time residents have to invest in transportation particularly through the use of cars (Moreno et al., 2021).

The concept of *complete communities* has emerged building on these strategies at the neighbourhood level. Ontario's 2020 growth plan identifies achieving complete communities as the first guiding principle for growth in the province (Ontario, 2020). The plan describes complete communities as "communities that are well designed to meet people's needs for daily living throughout an entire lifetime by providing convenient access to an appropriate mix of jobs, local services, public service facilities, and a full range of housing to accommodate a range of incomes and household sizes" (Ontario, 2020, p. 10). Complete communities are not a contemporary concept, however. Donaldson (2019) argues that the oldest complete community was recorded to have existed in the second century B.C. in Palestine and Syria where community members shared their property, meals, and religious rituals (Donaldson, 2019). Prior to the invention and commercialization of motorized transportation, residents of any community had to fulfill their daily needs within a small radius from their residences where they could walk or use non-motorized means. As settlement patterns result from transportation systems (Duany et al., 2010) prior to the commercialization of the automobile, all communities were complete. **So, what would a 21st century community need to be complete?**

Ohland and Brooks (2012) list quality education, access to good jobs, affordable housing, affordable healthy food, health services, artistic, spiritual, and cultural amenities, recreation and parks, meaningful civic engagement, and affordable transportation choices as essential elements of complete neighbourhoods. They emphasize the importance of opportunity areas that contain sufficient infrastructure to support the development of complete communities. These areas normally have smaller blocks and moderate density housing and/or jobs. (Ohland & Brooks, 2012).

Grant and Scott (2012) describe complete communities as communities that have "a mix of housing types and mixed uses in a compact form, often in association with public transportation nodes" (Grant & Scott, 2012, p. 137). They examine the tensions between contemporary planning policies - which advocate complete communities, compact form, intensification, mixed use, and mixed housing types - and development practices that reaffirm conventional homeownership of the detached house with the inherent automobile dependency as the Canadian dream (Grant and Scott, 2012).

Evenson and Cancelli (2018) focus on density as one of the factors that work with drivers of complete communities in creating "vibrant, inclusive, desirable places for people to live and work" (Evenson & Cancelli, 2018, p. 138). The Canadian Urban Institute has established six drivers of complete communities: walkability, built form diversity, green and open space, amenities, transit, and design (Evenson & Cancelli, 2018).

The Greenbelt Foundation's report Growing Close to Home: Creating Complete Rural Communities (2020) defines a complete community as "one that offers a full range of jobs, retail and services, housing options, transportation options, and public service facilities that meet people's needs for daily living throughout their entire lifetimes" (Greenbelt Foundation, 2020, p. 7). It discusses seven dimensions of achieving completeness in rural communities: growth management, housing, public and active transportation, economic development, character, agriculture and environment, and public consultation (Greenbelt Foundation, 2020).

This review of definitions and descriptions suggests that meeting people's daily needs locally is one of the main purposes of a complete community. In other words, there is a level of self-sufficiency that communities must have to be complete. To fulfill this purpose, complete communities have certain qualities and components, and Table 1 presents a synthesis of these qualities based on the previously highlighted body of work.

Another important aspect of complete communities is their sustainability and resilience. In current research, Wagner et al. (in review) establish that complete communities are contextual in nature and that they require flexibility and robustness as priorities may differ from one community to another. One of the dimensions they highlight for further exploration is complete communities' resilience and adaptability under changing circumstances (Wagner et al., 2022?). For complete communities to support the needs of residents over a lifetime, they must support the sustainability of the environment, otherwise, the substrate that supports these communities would be depleted, jeopardizing the health of these communities and their ability to adapt to changing conditions. Therefore, complete communities need to be environmentally sustainable.

Table 1

Synthesis of Complete Community Dimensions Based on Literature

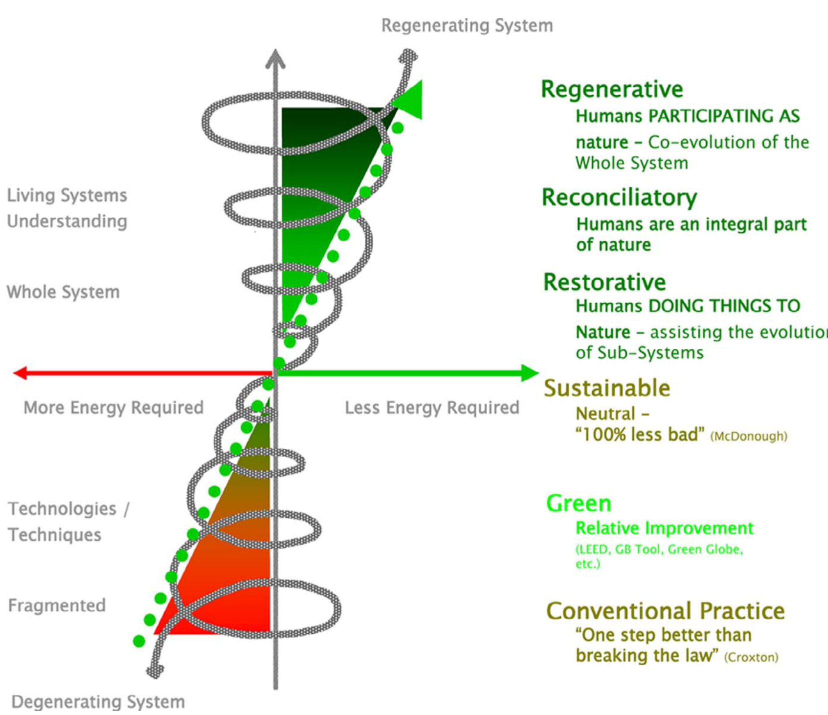
COMPLETE COMMUNITY DIMENSION	Ontario, 2020	Ohland & Brooks, 2012	Grant & Scott, 2012	Evenson & Cancelli, 2018	Greenbelt Foundation, 2020
Diverse housing choices for diverse groups	✓	✓	✓		✓
Diverse and affordable modes of transportation, including active transportation	✓	✓	✓	✓	✓
Amenities at a walking distance from residences	✓	✓	✓	✓	
Open green spaces at a walking distance from residences		✓		✓	
Spaces and opportunities for art and culture to flourish	✓	✓			
Good job opportunities		✓			✓
Meaningful civic engagement and public consultation		✓			✓
Diversity of built form and land use	✓		✓	✓	
High density and compact development			✓		✓
A look and feel that is unique to the community				✓	✓

Complete Communities are Regenerative

Environmentally responsible design encompasses a number of approaches that have been proposed and applied to varying degrees to the built environment, such as green design, sustainable design, and restorative design. Bill Reed (2007) maps the trajectory of environmentally responsible design approaches based on their energy requirements and impact on the ecosystem, from limiting the damage, eliminating the damage, restoration, to regeneration. A fragmented approach can only go so far as limiting the damage being done to the ecosystem, while restoring and regenerating ecosystems requires a living systems approach (Reed, 2007).

Figure 1

Trajectory of Environmentally Responsible Design (Reed, 2007)



Eliminating damage to the ecosystem is not sufficient for communities to meet the needs of their inhabitants over their lifetimes. In rapidly changing contexts, sustainability as a target is not fixed (Wahl, 2007). The work of fostering regeneration is not simply a variation of sustainability. Regeneration is a "dynamic process of co-evolution and a community-based process of continuous conversation and learning how to participate appropriately in the constantly transforming life-sustaining processes that we are part of and that our future depends upon" (Wahl, 2016, p. 40). This shift in the definition of sustainability from meeting fixed goals to a dynamic process is a shift from what Reed describes as a 'fragmented approach' to a 'living systems approach'. It is a shift from degeneration, through sustainability, toward regeneration.

A *regenerative design* approach focuses on the evolution of the system as a whole, with humans being part of that whole as active ecological participants (Reed, 2007). It is based on understanding and fostering the inner workings of ecosystems in ways that regenerate wholes rather than depleting their life supporting resources (Mang & Reed, 2020). This approach to design leads us to understand that, even when a design seems viable and possible to support by current environmental conditions, if implementing the design leads to the depletion of these supporting resources in the long run instead of regenerating them, it is not a viable design because it will ultimately lead to its own depletion. Similarly, a development is only viable when its implementation leads to the regeneration of the resources and environmental conditions that support it. Systemic health is an emergent property of such a regenerative system (Wahl, 2016)

As a community learns to understand the inner workings of the local and regional contexts that support it, and to participate in those contexts as a part of a whole, it adapts and learns to flourish within the opportunities and constraints presented by these contexts. It becomes part of the process of the regeneration of the whole, thus supporting the health and resilience of the total ecosystem.

Regenerative communities are health generating and resilient. When seen in this light, communities can only be truly 'complete' if they are regenerative.

Part 2:
What is Generative Design?

One of the emerging innovations for addressing complexity in architecture and urban planning is ***generative design***. This section starts with an overview of how generative design is defined in the literature, and which definition this report refers to. To showcase what generative design looks like in practice, a real-life project is described where a generative design process was followed to create design alternatives for a neighbourhood park.

Contents:

Generative Design Definitions

The introduction of CAD in the 1960's has undoubtedly revolutionized Architecture, Engineering, and Construction (AEC). Since then, numerous innovations have changed the role computers played in the design process. The evolution of CAD towards generative design can be summarized in four phases: computer-aided documentation, parametrization, visual programming, and generative design. Each of these phases builds on prior capabilities, and in some cases, renders these obsolete. I summarize the main characteristics of each phase in Table 2, and present a more detailed account in Appendix A.

Table 2

Evolution of Computer-Aided Design

PHASE	TIME PERIOD	DEFINING INNOVATIONS
Computer-Aided Documentation	**1960's - 1980's**	Introduction and commercialization of CAD systems that enable designers to digitally draw 2D and 3D forms using command lines and keyboard and mouse input
Parametrization	**1980's - 1990's**	Introduction of programming languages that can be used to describe geometry and components through parametric equations, and the introduction and commercialization of CAD systems based on these languages. This enables the creation of complex and coherent 3D models that are easy to revise
Visual Programming	**1990's - present**	Introduction of visual scripting languages and interfaces into architectural CAD software
Generative Design	**2010's - present**	Introduction of systems that bring together parametric design tools and optimization algorithms to enable performance-based generation and optimization of design solutions

As illustrated in Table 2, tools that enable working through a generative design process in architectural and urban planning contexts have become available relatively recently. However, much theoretical and practical work preceded the development of these computational tools. John Frazer's work on *generative evolutionary architectural systems* and Christopher Alexander's *pattern languag*e and *generative codes* are examples of such work.

John Frazer (2002) talks about a generative evolutionary paradigm in architecture that draws inspiration from how DNA defines the instructions for building a phenotype, not the phenotype itself, which allows for maximum variety in outcomes as the process is environmentally sensitive. Similarly, in a generative evolutionary paradigm, the architect's role is to describe the steps for creating the form, not the form itself, in a machine-assisted human creative process (Frazer, 2002).

Christopher Alexander (2005) also talks about a procedural, rather than a component-based, approach to building sustainable neighbourhoods. He describes these processes as generative codes that guide the organic unfolding of new or existing neighbourhoods in a way that allows the neighbourhood and its inhabitants to flourish (Alexander et al, 2005). What sets Alexander's generative codes apart is that they are procurement-driven rather than form-driven. Instead of describing a series of steps of how the geometry of a neighbourhood is created, Alexander's generative codes describe how the procurement process is carried out so that people have ownership of the place in a way that respects the land, people, and community. For example, one of the generative codes specify that users must physically play a role in laying out streets, dwellings, and public spaces, and that these layouts must be made directly on the ground before paper drawings are made (Alexander et al, 2005).

Based on this early work, generative design can be understood as a **context-sensitive design approach that focuses on describing the sequential steps for generating solutions, and allowing the solution to take form by responding to environmental conditions**. This approach has two variations based on the works described above:

- The process can be computer-assisted, which implies that the steps must describe how geometry will be generated in computational terms.
- The process can be user-led, which implies the steps can be defined in qualitative terms without specifying how geometry will be generated. Rather, users are left to explore what geometry fulfills their design objectives.

In the following years as CAD entered the parametrization phase, numerous design terms started to emerge and were sometimes used interchangeably and inconsistently. Caetano et al. discuss the distinction and the overlap between common terms related to computational design such as algorithmic design, generative design, and parametric design. They conclude that ***generative design* is a computational design approach that uses algorithms to generate designs, and where the correlation between these algorithms and the outcomes could be either identifiable or not**. *Algorithmic desig*n is therefore a subset of generative design. *Parametric design* uses parameters to describe a set of designs, and may or may not use these parameters to generate designs. Therefore, some, but not all, parametric designs can be considered generative (Caetano et al, 2020). This definition of generative design aligns with the definition based on the early work discussed, but narrows it down to the computer-assisted approach.

Within this definition of generative design as a computer-assisted approach, there are variations based on the specific generative design techniques used in generating and exploring solutions. Singh and Gu (2012) review five generative design techniques commonly used in architecture and propose an integrated framework that brings these techniques together into an interactive system. These techniques are shape grammars, L-systems, cellular automata, genetic algorithms, and swarm intelligence (Singh & Gu, 2012).

A more specific definition of generative design builds on the use of one of the generative design techniques: genetic algorithms (Holland, 1975) which are evolutionary techniques inspired by the process of evolution (Singh & Gu, 2012). Autodesk's definition of generative design is based on the use of genetic algorithms as optimization algorithms in design problems. From that perspective, generative design is defined as **a collaborative design process between humans and computers where designers define parameters and computers produce design alternatives, evaluate them against quantifiable goals, improve the alternatives by using results from previous ones and feedback from the designer, and rank the results based on how well they achieve the designers' original goals** (Autodesk, 2021a). This definition narrows down previous definitions by specifying the kinds of algorithms used in the process:

- *Generators* define the steps for creating the geometry of the solution; they can generate a large number of design alternatives by varying input values.
- *Evaluators* are the design goals translated into metrics; they define the steps for assigning a numerical score for each design alternative under each metric.
- *Solvers* automatically run the script that contains both Generators and Evaluators numerous times to generate and evaluate design alternatives, and oftentimes optimize these alternatives through multiple generations (Autodesk, 2021b).

GENERATIVE DESIGN DEFINITIONS (CONT.)

Based on these definitions, at the broadest level, generative design could either be computer-assisted or not, as long as a series of steps is what drives the design process. At the most specific level, computer-based algorithms define these steps, and these steps involve a process of search and optimization. This project addresses generative design at the most specific definition, but keeps the door open to incorporate aspects of the broader definitions when needed to fulfill the purpose of the project; finding the bridge between generative design and regenerative design.

Generative Design Workflow

As a new approach to design that combines the power of computation, different workflows are being explored for incorporating generative design into existing design processes. The following generative design workflow is based on three recent projects: the new Autodesk office space in Toronto (Nagy et al, 2017a), Autodesk University conference hall in Las Vegas (Nagy & Villaggi, 2020), and a residential neighbourhood development project in Alkmaar, Netherlands (Nagy et al, 2018).

1. Pre-Generative Design

Similar to any design process, in generative design, designers start with understanding the context, goals, and constraints of the problem. Based on the problem context, an architectural or urban concept is established, but unlike typical architectural or urban planning projects, the concept is defined as an algorithm, or a series of steps of how forms will be generated.

2. Geometry Generation Model

In this step, designers create a system that can generate geometry based on the design concept. The model is built using a parametric design tool. The model should be built parametrically so that the search algorithm can generate design alternatives by changing the parameters.

3. Design Metrics

Based on the goals identified in the first step, designers define the metrics that will be used to evaluate the performance of solutions against these goals. The metrics must be defined quantitatively so that they are exposed to the search algorithm for the evaluation of solutions, therefore, project objectives are often divided into three groups:

- easily quantifiable objectives that can be calculated using existing tools;
- qualitative objectives that can be quantified by building custom tools; or

- qualitative objectives that cannot be quantified, and which need to be addressed outside of generative design (Nagy et al, 2017a).

Designers therefore must make a judgment call on what goals and metrics will be translated and built into the generative design model, and which ones will be left to be evaluated outside of the model.

4. Design Space Exploration

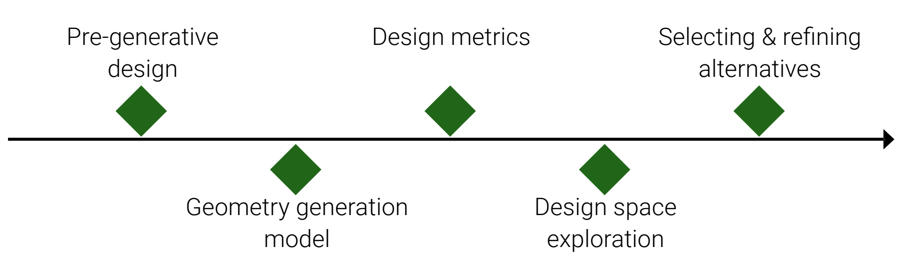
This step is performed using a search algorithm to automatically explore the design space by generating designs over a number of generations, evaluating the solutions in each generation, and using the parameters of high performing solutions to optimize the next generation of solutions. This often results in hundreds of design alternatives that are ranked based on their performance against the defined metrics.

5. Selecting and Re ining Alternatives

Designers then investigate, rank, and compare solutions based on their scores, and based on other performance criteria that were not included in the generative design model. Tradeoffs between design objectives can be explored through different visualization strategies. The preferred solution is selected and further refined as needed.

Figure 2

Generative Design Workflow



Generative Design In Practice

This section describes a real-life project where a generative design process was followed to create design alternatives for a neighbourhood park. This project is based on a Mitacs internship where I worked with a group of researchers and advisors from OCAD University, University of Toronto, Autodesk Research, and the Daniels Corporation, to explore how generative design can be applied in urban planning contexts. The project was entitled: *Applying Generative Design to Complete Community Planning*.

Project Background

The city of Brampton, Ontario, has an ambitious vision for 2040 to be a major transit-oriented work/live core for business, commerce and leisure. The vision sets Brampton within a green park framework and includes diversified centres, revitalized existing neighbourhoods, complete new neighbourhoods, and a rapid transit network (Brampton, 2022). Within this vision, Daniels plans to create a complete community development near Mount Pleasant station. The site presented a good opportunity to explore how complete community metrics can be translated and incorporated into a generative design process to design a neighbourhood or parts of a neighbourhood.

The development is planned to be built on a 20-acre site surrounded by a number of amenities such as schools, a small grocery store, a public library, a civic square, a mosque, a church, a number of cafes and restaurants, in addition to the Go Station which is a key connectivity point that serves the neighbourhood and surrounding areas. The development itself consists of two high rise apartment buildings, a mix of townhouses, open green spaces, shared amenities, and a neighbourhood park. When our team started working on the project, two out of four of the residential blocks were finalized in terms of planning. The remaining blocks and the neighbourhood park were still under design development. This presented an opportunity to work through a generative design process to explore how these blocks can be improved. Daniels' priority was to finalize the design of the park first then finalize the remaining blocks. As I was just getting started with learning the tools, it made sense to start working on a smaller scale sub-project, so the first phase of our work focused on Mount Pleasant Village neighbourhood park.

The Workflow

The overall objective of the project was to explore how a generative design process can facilitate the design of complete community typologies, and Mount Pleasant Village neighbourhood park was used as a site to start that inquiry. The generative design process followed was informed by the workflows of designing the new Autodesk office space in Toronto (Nagy et al, 2017a), the Autodesk University conference hall in Las Vegas (Nagy & Villaggi, 2020), and a residential neighbourhood development project in Alkmaar, Netherlands (Nagy et al, 2018). Our workflow consisted of the following steps:

1. Gathering requirements and constraints
2. Defining goals
3. Defining metrics
4. Building the Model
5. Generating, evaluating, and evolving solutions
6. Selecting and refining solutions

The process was less linear in practice, with many steps occurring simultaneously and numerous iterations occurring between steps. This was accompanied by ongoing consultations with project advisors and site developers.

1. Gathering Requirements and Constraints

Consultations with the developers and documentation review informed the requirements and constraints of the project.

Constraints

The new design alternatives for the park must maintain:

- a predefined park boundary that the park’s amenities should fit within; and
- a service corridor that runs across the south side of the park where no permanent structures or vegetation should be placed.

Requirements

The park program was flexible as long as it included a gathering area, a cooking area, a children's area, sitting areas, open spaces, and walkways.

Once we understood the requirements and constraints of the park, our strategy for the research project was to create a model that generated a variety of park layouts aligned with the constraints and requirements identified, and to rank these layouts based on how well they fulfill the overall project goals.

2. Defining Goals

Consultations with the project team revealed the following primary goals the development aims to fulfill:

- improving access and walkability;
- creating a complete community; and
- improving social cohesion in the neighbourhood.

To identify specific objectives to be met by the design alternatives, we conducted a literature review around complete communities, walkability, and social cohesion. The outcome of this review combined with team consultations resulted in identifying the following goals to inform the generative design process and the evaluation of the generated solutions:

- Walkability
- Accommodation of diverse abilities
- Year-round use
- Safety
- Accommodation of diverse activity levels
- Environmental sustainability

3. Defining Metrics

In a generative design process, performance criteria must be exposed to the search algorithm as a numeric quantity (Nagy et al, 2017a). Therefore, the identified goals in the previous steps needed to be translated into computable metrics to be built into the model. This process of translating goals into metrics took multiple iterations as most of these goals were qualitative and we found that some of them were best evaluated outside of the generative design workflow.

Walkability

Delgado-Ron (2020) presents a holistic lens to understand walkability from a human-centred view. In terms of the physical space, walkability requires the absence of obstacles between origin and destination, proximity between origin and destination, and safety of the route (Delgado-Ron, 2020). While proximity and absence of obstacles can be easily quantified, safety and human factors are more complex. Walking proximity between key destinations was therefore used as a metric to evaluate the performance of solutions in terms of facilitating walkability. We called this metric *traversability* to indicate that its focus is limited to distance rather than the holistic concept of walkability.

Accommodation of Diverse Abilities

This goal was built into the *traversability* metric by measuring walking distance between key destinations on paved paths, to accommodate different mobility needs.

Year-Round Use

This goal was found to be better evaluated outside of a generative design process as it is related to the park program.

Safety

Safety is another goal that is highly qualitative and encapsulates multiple dimensions. We called the metric we used to evaluate performance towards this goal *road safety* and it was specific to the distance of children's play areas from the main road. Other dimensions of safety had to be evaluated outside of the generative design model.

Accommodation of Diverse Activity Levels

The metric used to evaluate performance against this goal was called the *tranquility* metric, and it was specific to locating desirably quiet amenities far from high-noise amenities.

Environmental Sustainability

This goal needed to be redefined in more specific terms that were relevant to the park and usable in the generative design process. Permeable ground cover was selected as a more specific and achievable objective.

Other Metrics

The *cohesion* metric was later added to address the social impact of the project, and the *amenity size* metric was added to address the programmatic requirements of the park.

Table 3 summarizes the final list of objectives and the metrics used to evaluate these objectives.

Table 3

Park Design Objectives and Metrics

OBJECTIVE	METRIC
Lay out park amenities and paths to encourage walking through the park, both as a destination and a neighbourhood connector.	*Traversability*, measured as the average ratio of the travel distance around the park to the travel distance through the park between key points in the park.
Assign the appropriate square meters for each amenity use.	*Amenity size*, measured as the average deviation between the resulting amenity sizes and the size assigned to each amenity in the original architect-designed layout.
Lay out park amenities to increase opportunities for frequent encounters between park visitors, facilitate parental supervision of the playground, and activate the park throughout different times of the day.	*Cohesion*, measured as the average distance between: • shade pavilion and playground; • shade pavilion and vegetable garden; and • playground and flexible playfield.
Lay out park amenities to separate the kids playground and flexible play field from the main road.	*Road safety,* measured as the average distance between: • flexible play field and main road; and • playground and main road.
Lay out park amenities so that amenities with low noise tolerance are separated from high activity amenities.	*Tranquility*, measured as the average distance between: • vegetable and sensory gardens; and • playground and flexible playfield
Reduce the coverage of non-permeable ground cover throughout the park.	*Permeable cover*, measured as the ratio of the area of impervious paths in SQM to the total park area in SQM, divided by 30% as a preferred maximum impervious ground cover.

4. Building the Model

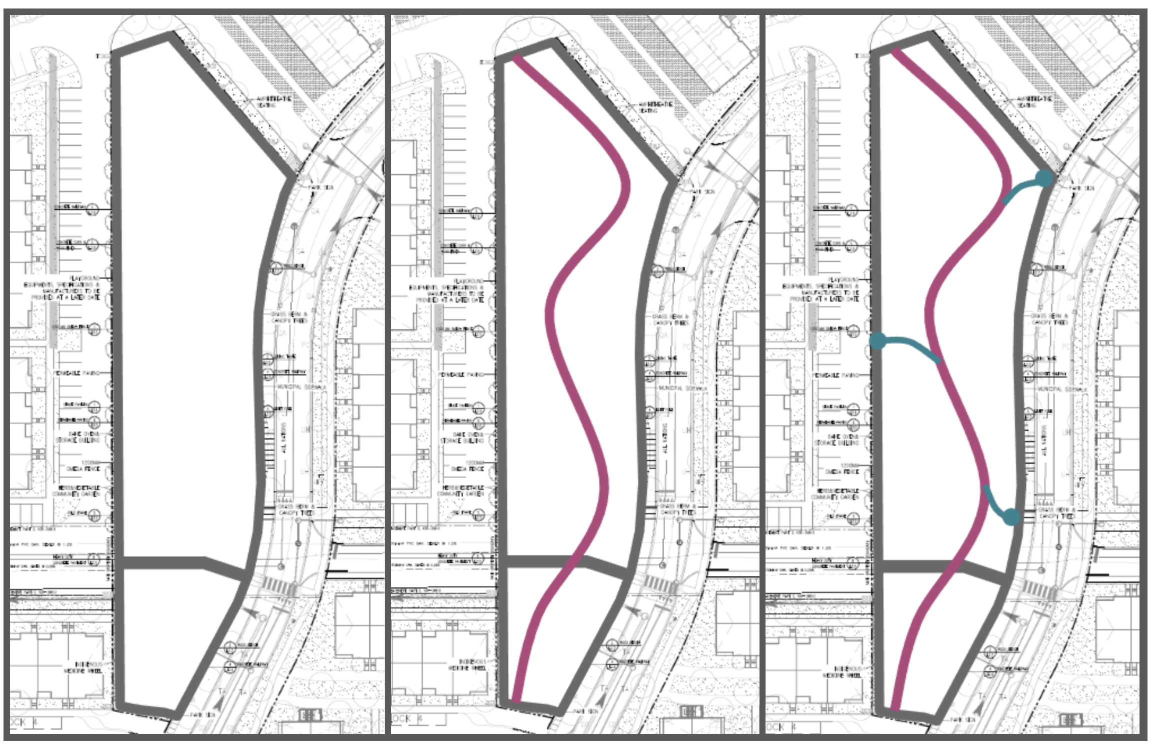
In this project, the model was built using Dynamo Sandbox and a number of custom packages. Two generators and six metrics were built into the model.

Generators

The first generator was specific to generating the layout of the park paths. The sidewalks around the perimeter of the park and the service corridor were fixed. The generator was designed to create a primary curved path that runs longitudinally through the park, then it created secondary paths that connect key points on the park perimeters to the primary path, providing connectivity between the two sides of the park.

Figure 3

Path Generator Concept - Left: Fixed Park Paths, Centre: Primary Path, Right: Secondary paths



The second generator created the amenity areas. It worked by generating a number of random sample points throughout the park then creating Voronoi tessellations based on these points. Amenities were then assigned to the polygons based on their relative size. The two generators were combined to create numerous complete park layouts.

Figure 4

Amenity Generator Concept - Left: Sample Points, Right: Voronoi Tessellations

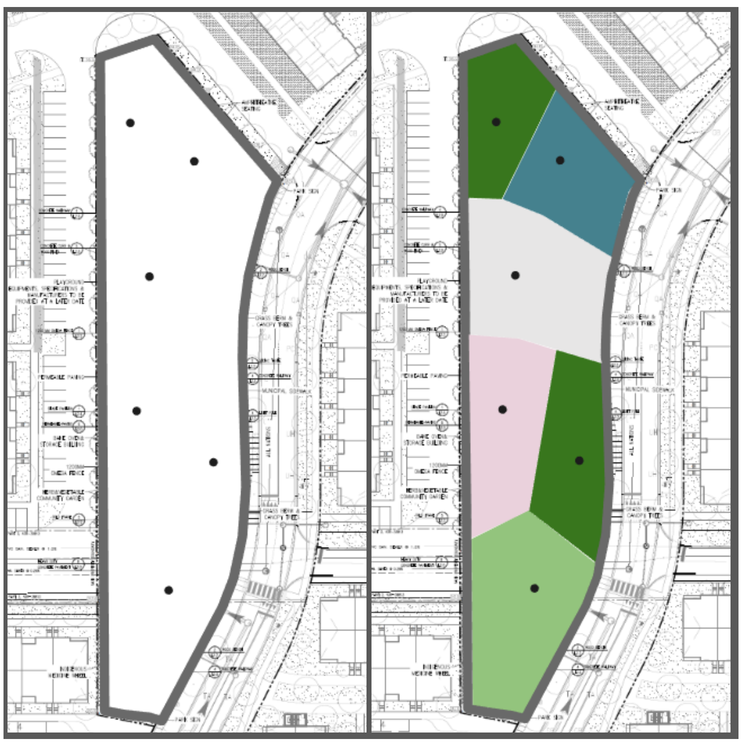
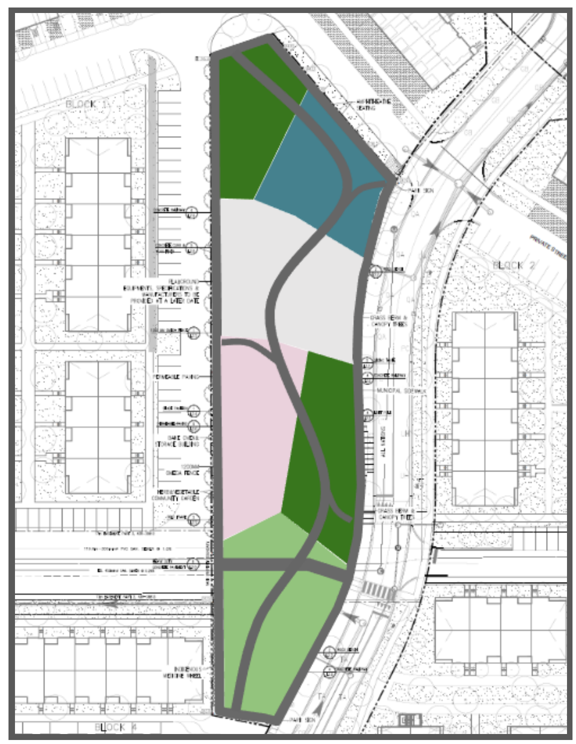


Figure 5

Amenity and Path Generators Combined



Evaluators

An evaluator algorithm was built for each of the six metrics defined earlier. The evaluators were built using standard Dynamo nodes in addition to nodes from the VASA toolkit which provides specialized operations to perform different space-related analyses in 2D and 3D models such as pathfinding, visibility, and acoustics.

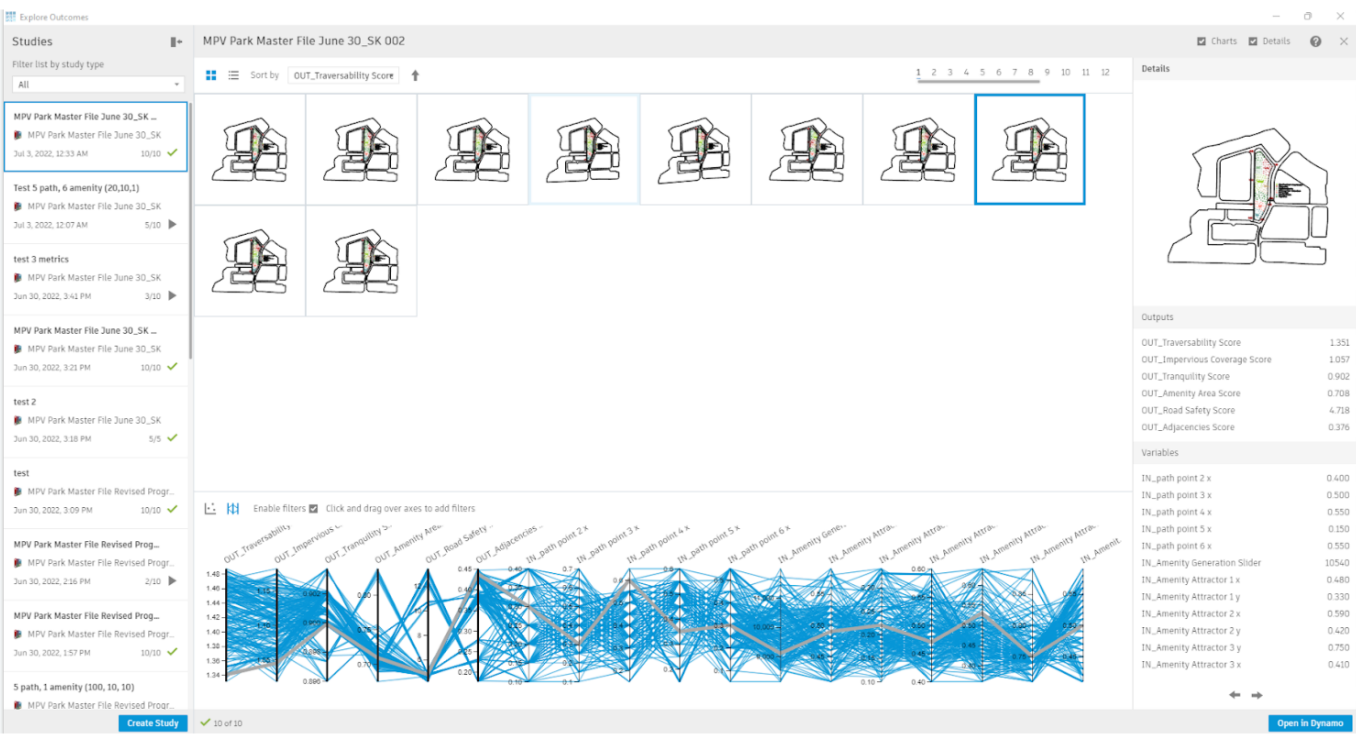
5. Generating, Evaluating, and Evolving solutions

To test and tweak the model, a number of studies were run using Generative Design for Dynamo with the ‘optimize’ solver. The optimize solver creates multiple 'generations' of a design, evaluates these designs based on the defined metrics, and uses the input configuration from the top performing designs to optimize the next generation (Autodesk, 2021c).

A final study was run with a population size of 500 over 10 generations, which meant 5000 design alternatives were generated, evaluated, and ranked. We selected a sub-group of the higher performing solutions across multiple metrics for refinement and final comparison.

Figure 6

Results of a Generative Design Study Done in Generative Design for Dynamo



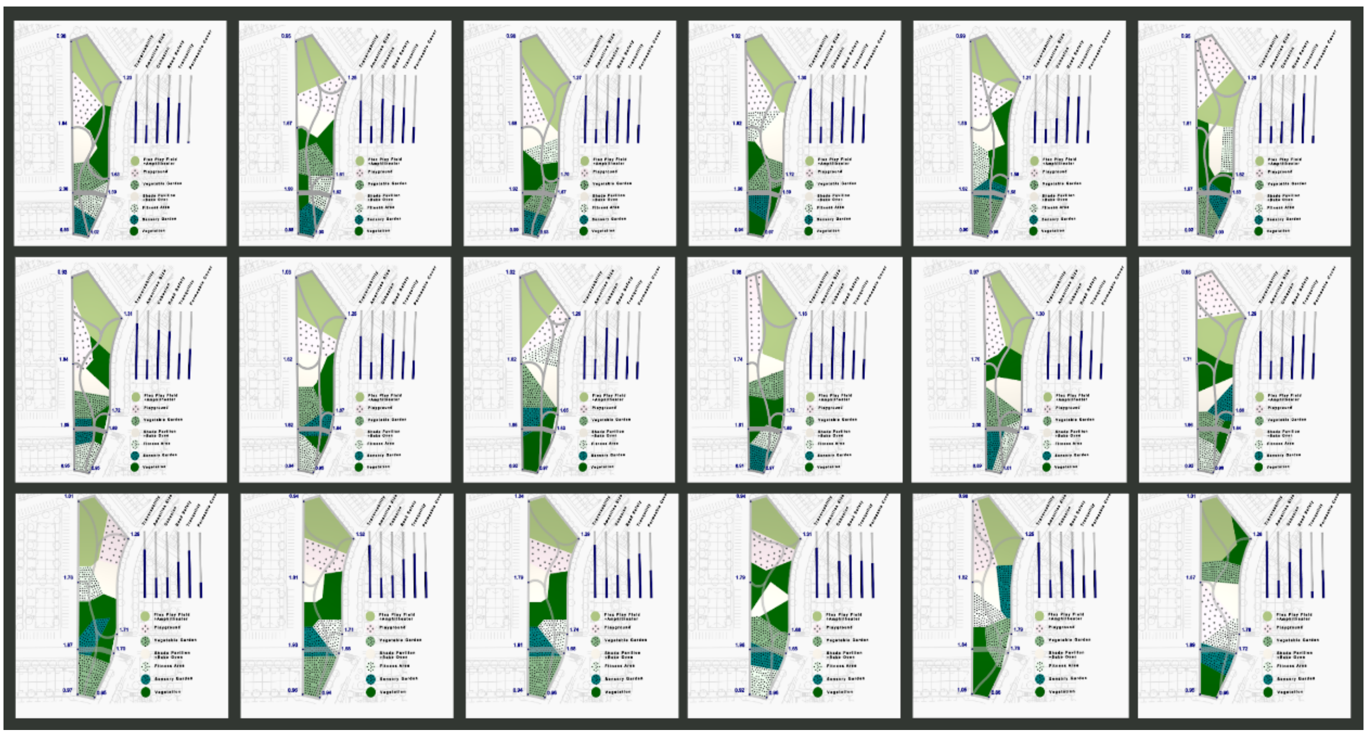
Note: Left side of the interface shows all generative design studies run previously. Top middle part of the interface shows thumbnails of all solutions generated through the current study. Top right corner of the interface shows a thumbnail of the selected solution. Bottom right corner shows numerical inputs and outputs of the selected solution. At the bottom, a line graph plots all design alternatives based on to their performance in different metrics (outputs) and their inputs.

6. Selecting and Refining Solutions

Since the amenity layouts and path layouts were generated using two separate generators, high-performing solutions needed to be refined to ensure amenities and paths were cohesively laid out in the final solution. From the previously described study, six solutions were selected. Refining solutions involved manually modifying paths and amenity layouts and switching the locations of some amenities to improve performance against specific metrics.

Figure 7

A Sub-Group of Park Layouts Generated through Generative Design for Dynamo



For example, the solution outlined in Figure 10 was selected because it had a high score in *cohesion*, *road safety*, and *tranquility*. The path layout also loosely corresponded to amenity boundaries, so there was an opportunity for refining the layout to create a better flow. The problem with this layout was that the paths intersected many amenities. Refining this solution improved cohesion as the playground and vegetable garden became adjacent to the gathering area. It also improved road safety as the flexible playfield was separated from the main road by vegetation. However, this reduced *permeable cover* and *amenity size* scores.

The process of refining alternatives was applied to all six alternatives and presented to the team for final review and discussion. The visualization scheme was evolved to improve legibility and facilitate comparison between the new alternatives and the original layout. The early visualization scheme shown in Figure 8 was used throughout the development of the model, but it was challenging to read for people with colourblindness. Another scheme was developed to improve legibility by introducing textures and high contrast, shown in Figure 9. In the final scheme, the scores of the original layout were visualized next to the new solutions' scores to facilitate comparison and discussion. This scheme is shown in Figures 10 and 11.

Team discussions revealed the preferred solution to be Figure 11. This solution had a good flow and performed quite well in most metrics. It performed relatively highly in the *traversability, cohesion, road safety,* and *tranquility* metrics. To improve *amenity size*, the designer can further refine and adjust the size of amenities to match the required program. To improve *permeable cove*r, some or all paths can be paved with permeable paving instead of impervious materials.

Figure 8

Early Visualization Scheme was Inaccessible to People with Colourblindness

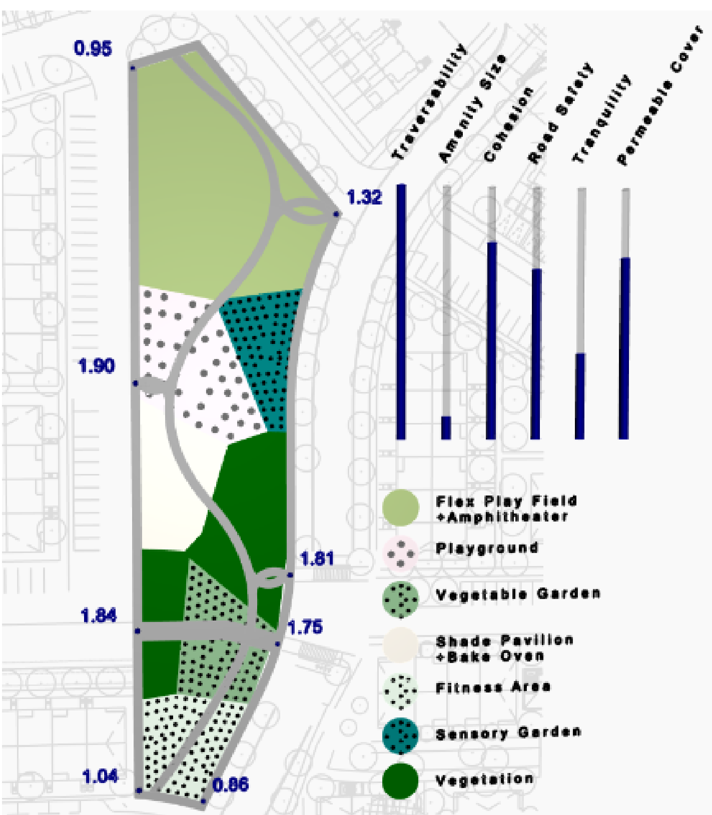


Figure 9

Visualization Scheme to Improve Legibility of Amenity Boundaries

Figure 10

Selected Park Layout - Computer Generated Layout

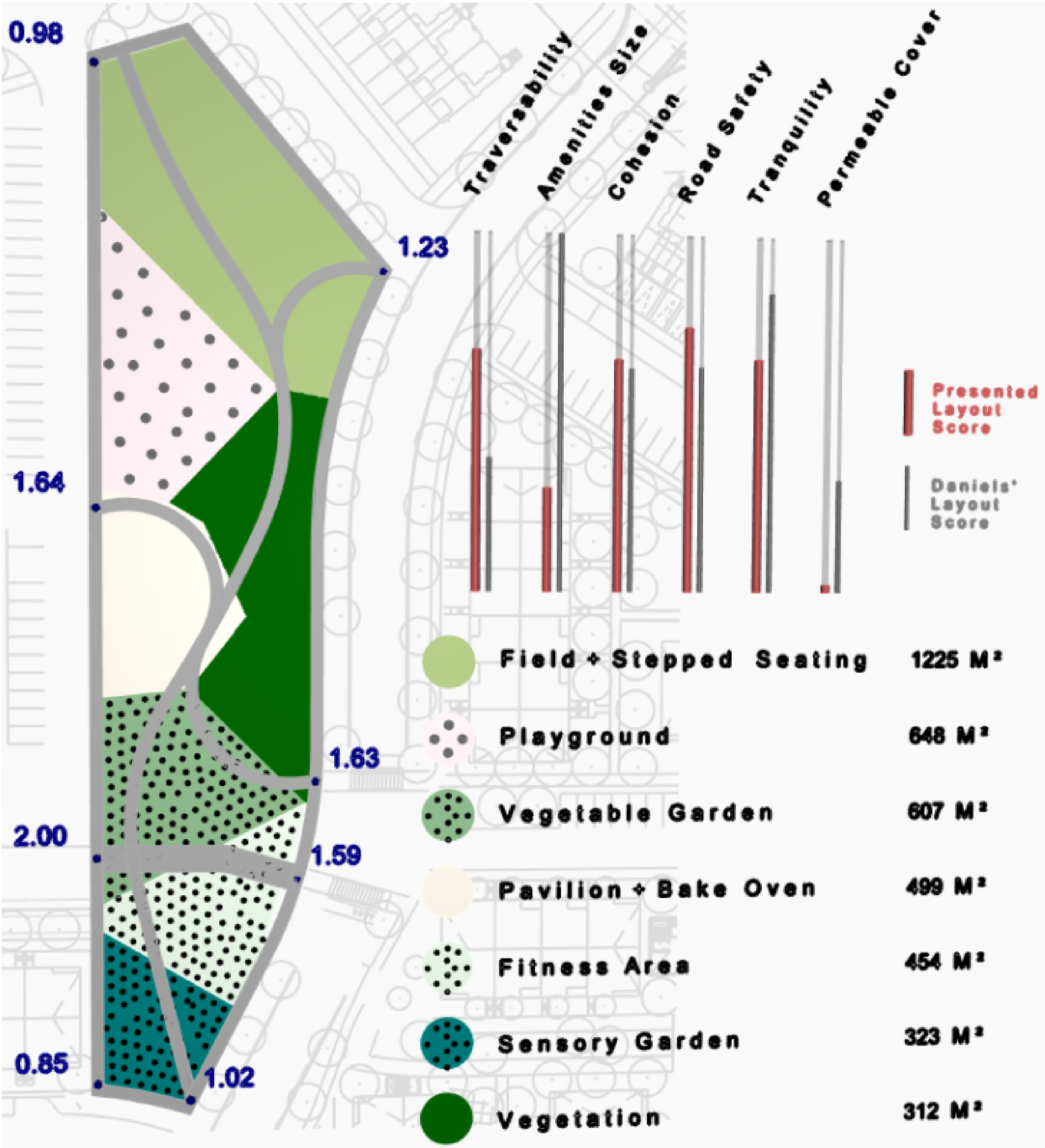
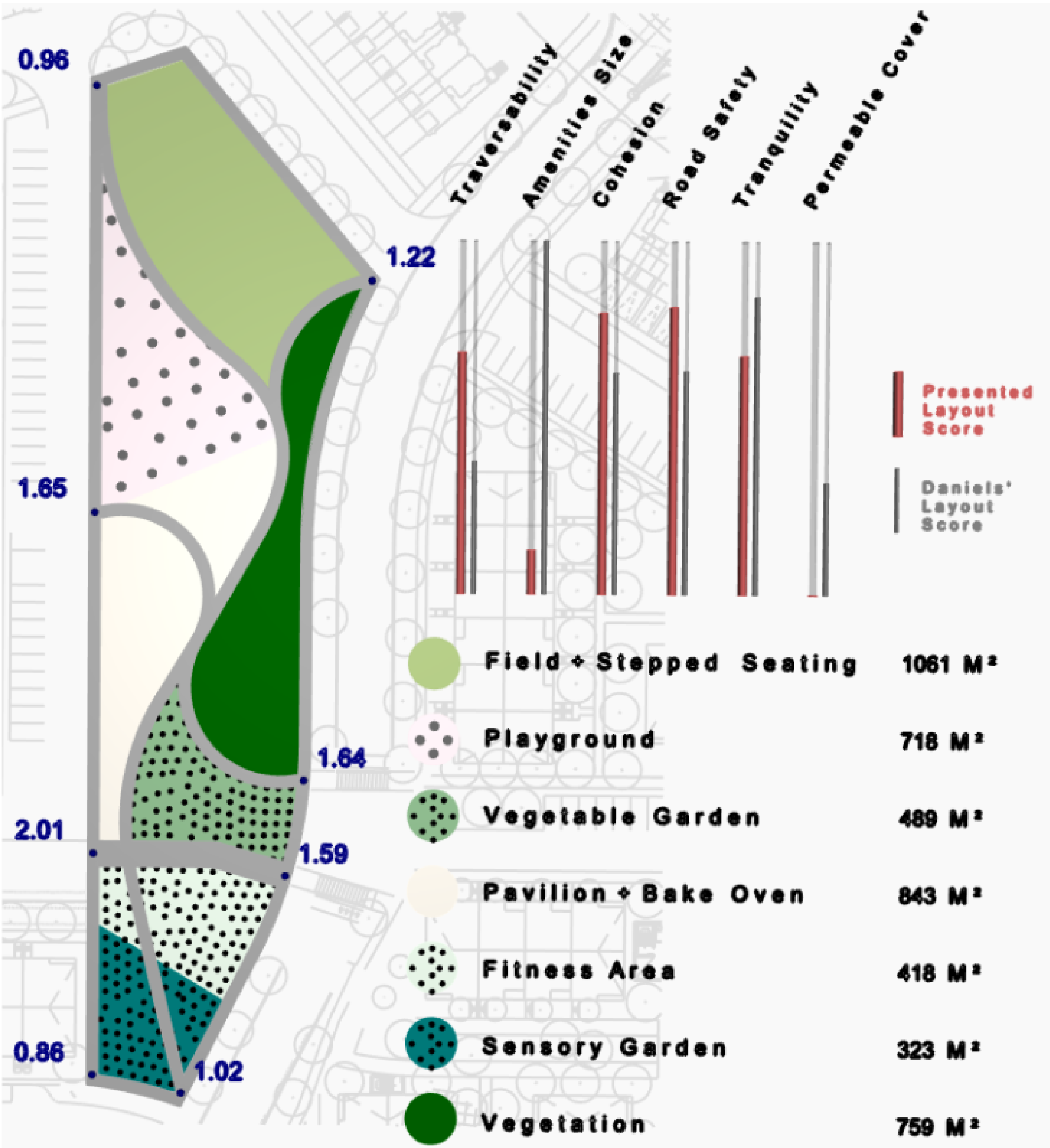


Figure 11

Selected Park Layout - Layout Refined by Designer



Takeaways: The Potential of Generative Design

In its broadest definition, generative design is a context-sensitive design approach that focuses on describing the process of generating solutions, and allowing solutions to take form by responding to environmental conditions. One of the approaches to undertake such a process is through human-computer collaboration where human designers define project goals and processes for generating solutions, and computers produce design alternatives, evaluate, improve, and rank them based on how well they achieve design goals.

Parametric design has introduced a new approach to designing built environments which makes producing design alternatives, propagating design revisions, and creating complex geometry more efficient. The introduction and commercialization of generative design could significantly enhance those features, in addition to introducing new ones such as computationally improving the fit between design alternatives and objectives and automating design development.

These affordances could gradually shift designers' role from designing geometry to coding algorithms that generate geometry. As the workload of generating design geometry shifts to computers, designers would be able to spend more time understanding the problem context, identify solution strategies, and engage with project stakeholders. The complexity of the problems we face today requires involvement of multiple stakeholders and deeper understanding of problems before taking action, which makes generative design a potential pathway for addressing this complexity.

However, achieving good results through generative design requires shifting from a traditional design approach that most designers are trained in, to a generative design approach. Moreover, designers still have to build geometry generators to perform complex generative design studies. Both aspects are effort-intensive and require substantial un-learning and re-learning on the part of designers. **Could this shift designers' focus away from other vital design activities?** Running generative design studies also requires the translation of design objectives into quantitative metrics. **Could this also narrow designers' attention towards computable objectives and algorithmically generable design solutions, and away from complex qualitative objectives and design solutions that do not follow a rule-based geometry?**

How might we achieve the full potential of shifting towards a generative design approach in addressing complex contexts, given the possible unintended consequences that might result from this shift?

Part 3:
Why Generative Design?

Generative design has the potential to revolutionize the way we design built environments through computationally improving the fit between design alternatives and objectives and automating design development. This section presents a review of recent generative design work in architecture and urban planning, focusing on the advantages of developing and following a generative design process in similar contexts. The section concludes with a discussion of three concerns around generative design from complexity and regenerative design perspectives.

Contents:

Advantages of a Generative Design Process

The increased technological availability of generative design tools combined with the potential offered by these tools make generative design a promising area of research and innovation to address complex problems. The use of generative design in architectural and urban design projects has been the focus of numerous studies over the last decade. These studies highlight the following advantages of a generative design process summarized in Table 4.

Table 4

Advantages of a Generative Design Process Based on Literature

ADVANTAGES	Caldas, 2006	Toker and Pontikis, 2011	Gerber & Lin, 2014	Tapias & Schmit, 2014	Charalampidis, 2015	Giedrowicz, 2015	Nagy et al., 2017	Nagy et al., 2018	Singh & Gu, 2018	Chang et al., 2019	Ridolfi & Saberi, 2019	Walmsley & Villaggi, 2019
Generating novel solutions				✓			✓	✓		✓		
Increasing the efficiency of design processes			✓				✓	✓	✓			
Incorporating performance criteria into the design process	✓		✓	✓			✓	✓	✓	✓	✓	
Optimization of solutions for competing objectives			✓				✓	✓	✓		✓	
Improving environmental performance of built environments		✓		✓	✓	✓		✓		✓	✓	
Managing complexity			✓					✓		✓		✓

Generation of Novel Solutions

While designers are able to come up with novel solutions to simple design problems, complex contexts with multiple stakeholders and conflicting goals are more difficult to resolve through traditional design processes. Nagy et al. argue that this leads designers to rely on intuition and prior experience, which limits the potential for exploring novel solutions. They highlight the benefits of a collaborative design process between human designers and computers in discovering innovative solutions beyond the ones that can be found through human intuition (Nagy et al, 2018). For example, Tapias and Schmitt propose a generative design methodology to explore the relationship between outdoor thermal comfort and building geometry. Their method systematically translates urban climate data into design alternatives to support climate sensitive urban growth (Tapias & Schmitt, 2014). Such methodologies that reduce designers' biases by directly linking geometry generation with performance criteria can result in novel solutions that would not have otherwise been explored through human intuition alone.

Increasing the Efficiency of Design Processes

The ability to generate and explore a large number of design alternatives in a limited amount of time is one of the main incentives to explore the application of a generative design process for designing the built environment (Singh & Gu, 2012). One of the main components of a computational generative design process is parametrically modeling the design system that generates geometry. The parametric model describes geometric forms in terms of parameters which, when changed, produce a different geometry. This enables the rapid generation of a multitude of design alternatives by manipulating parameters, thus automating some aspects of design exploration and shortening design exploration latency (Gerber & Lin, 2014).

In exploring the use of generative design for relating urban geometry with energy performance, Chang et al. argue that a performance-based approach is needed to design sustainable urban environments, and that one of the challenges to such an approach is that in every urban design project, there are thousands of design alternatives that cannot be explored due to time constraints. To address this challenge, they propose a methodology which incorporates machine learning and parametric modeling to generate all possible design alternatives within specific site constraints. They apply this methodology to the design of a campus building, using sky opening, solar radiation, and energy consumption as performance metrics to evaluate the generated solutions (Chang et al, 2019). While most generative design processes do not aim to generate all possible design solutions, they all take advantage of computational powers to generate a larger number of design alternatives than is possible to generate by human designers alone. For example, when designing Autodesk's office space in Toronto, 10,000 design layouts were generated and evaluated (Nagy et al, 2017a), and in exploring alternative layouts for a neighbourhood in Alkmaar, Netherlands, through generative design, a total of 40,000 design alternatives were explored (Nagy et al, 2018).

Incorporating Performance Criteria into the Design Process

The parametrization of geometry generation provides the opportunity for incorporating performance criteria and design objectives as part of the design process (Gerber & Lin, 2014). This allows the designer to define performance criteria to evaluate solutions against. However, these criteria must be both quantifiable and computable for the algorithm to consider and apply to the solution space (Nagy et al, 2017a).

Most generative design studies reviewed in this project have used quantitative and computationally calculable metrics as performance criteria such as:

- energy use intensity (Caldas, 2006; Gerber & Lin, 2014);
- natural lighting (Caldas, 2006; Nagy et al, 2017a);
- solar radiation and shading (Nagy et al, 2018; Charalampidis & Tsalikidis, 2015; Chang et al, 2019);
- size of sky openings (Chang et al, 2019);
- topography (Charalampidis & Tsalikidis, 2015);
- allocation of planting zones based on water runoff (Charalampidis & Tsalikidis, 2015);
- urban microclimate (Tapias & Schmitt, 2014); and
- financial metrics such as profitability and net value (Gerber & Lin, 2014; Nagy et al, 2018).

Some studies have translated qualitative criteria into quantitative ones. For example, in Autodesk's new office space in Toronto, workstyle preferences were incorporated into the generative design process by surveying future occupants about their spatial needs, such as the people and amenities they want to be close to, and their preferred ambient conditions such as acoustics and lighting (Villaggi et al, 2017). Another example is the incorporation of desirable high activity zones in both Autodesk's new office and Autodesk University's 2017 Exhibit Hall layout. Travel patterns between key points in the spaces were used as an indicator of the levels of activity in different areas (Nagy et al, 2017a; Nagy et al, 2017b; Nagy & Villaggi, 2020). In both examples, highly subjective and qualitative features were translated into quantitative metrics for the search algorithms to rank and optimize solutions towards.

Optimization for Competing Objectives

The incorporation of performance criteria into the parametric model enables the optimization of solutions based on these criteria. This is achieved through optimization algorithms that search through possible solutions to discover optimal parameters that result in maximizing performance (Nagy et al, 2017a). Instead of generating an optimal solution across all objectives, the purpose of optimization in generative design is to find better-fit solutions and provide an environment where better-informed decisions around tradeoffs can be made (Gerber & Lin, 2014; Nagy et al, 2018; Walmsley & Villaggi, 2019; Ridolfi and Saberi, 2019). This is considered one of the key advantages of using generative design in addressing complex solutions with competing objectives.

Gerber and Lin describe a generative design methodology that combines parametric modeling with multi-objective optimization to explore tradeoffs between spatial program compliance, energy use intensity, and financial net value (Gerber & Lin, 2014). Nagy, Villaggi, and Benjamin describe a generative design process to design a residential neighborhood in Alkmaar, Netherlands, with two competing objectives of cost and potential energy generation of the site (Nagy et al, 2018). These studies highlight the value of generative design in bringing to the surface tradeoffs between different objectives and finding better-fit solutions.

Environmental Performance

The affordance to optimize design alternatives for competing criteria through generative design provides an opportunity for developing environmentally sustainable built environments, and numerous studies explore the role of generative design in improving environmental sustainability of buildings. For example, Tapias and Schmitt's generative design methodology aims to optimize building geometry for thermal comfort as a contributor to urban livability and vitality, as promoting the use of outdoor spaces has physical, environmental, economical, and social benefits (Tapias & Schmitt, 2014). The Generative Landscape Design System (GLDS) proposed by Charalampidis and Tsalikidis aimed to increase the ecological performance of the design solution by optimizing the topography and layout for solar radiation, water runoff, and shading, which are factors that impact vegetation growth and landscape visitors (Charalampidis & Tsalikidis, 2015). The generative design process for designing the residential neighbourhood in Alkmaar aimed to maximize both the potential energy harvested through solar panels and the profitability of the project for the purpose of minimizing the environmental impact of the development (Nagy et al, 2018).

Addressing Complexity

The affordance to optimize design alternatives for competing criteria opens the door to one of the most ambitious objectives behind developing generative design tools for the built environment: managing complexity. Urban planning projects involve multiple disciplines and a large number of stakeholders with complex and interdependent needs and motivations, making urban planning a highly complex context to work with. Walmsley and Villaggi state that, as a framework that combines digital computation and human creativity, generative design has the potential to aid in the "management and structuring of complexity through the definition of goals that can represent the interest of different stakeholders" (Walmsley & Villaggi, 2019). The semi-autonomous generation and exploration of design alternatives allows "deeper exploration of complex design spaces" (Nagy et al, 2017a, 1.2 Beyond parametric) and gives designers the "ability to manage complex processes and a multitude of input variables" (Qeisi & Alalwan, 2021, p. 1).

Observations on the Advantages of Generative Design

Generative design is often approached from an optimization perspective. As seen in the previous discussion, generating a large number of design alternatives within a short amount of time, shortening design exploration latency, and finding optimal tradeoffs between objectives in the solutions space are some of the key motivations for following a generative design process. The proliferation of the smart city paradigm around the same time when generative design was emerging could have influenced this focus on optimization. Smart cities depend on the collection of a large amount of data from various sources to optimize urban infrastructure systems (Finger & Portmann, 2016). To support urban planning in this era, generative design continued to evolve around a comparable approach to efficiency.

The integration of information and communications technology (ICT) into the built environment does not have to be limited to top-down management approaches. While smart cities, in their most techno-centric definitions, focus on management of resources, other definitions bring attention to citizen engagement (Preston et al., 2010) and governance (Mostashari, 2011) enabled by ICT. Finger and Portmann (2016) describe three models of integrating technology into urban environments which differ in terms of attention towards people's involvement and role in the system.

The first model they describe makes optimal use of all interconnected information available through information and communications technologies to better control, manage, optimize, and improve the efficiency of urban infrastructure systems, such as water, public safety, traffic, buildings and energy. Finger and Portmann refer to this as the smart city concept and argue that it is rooted in top-down management and is thus effective in addressing urban efficiency challenges (Finger and Portmann, 2016).

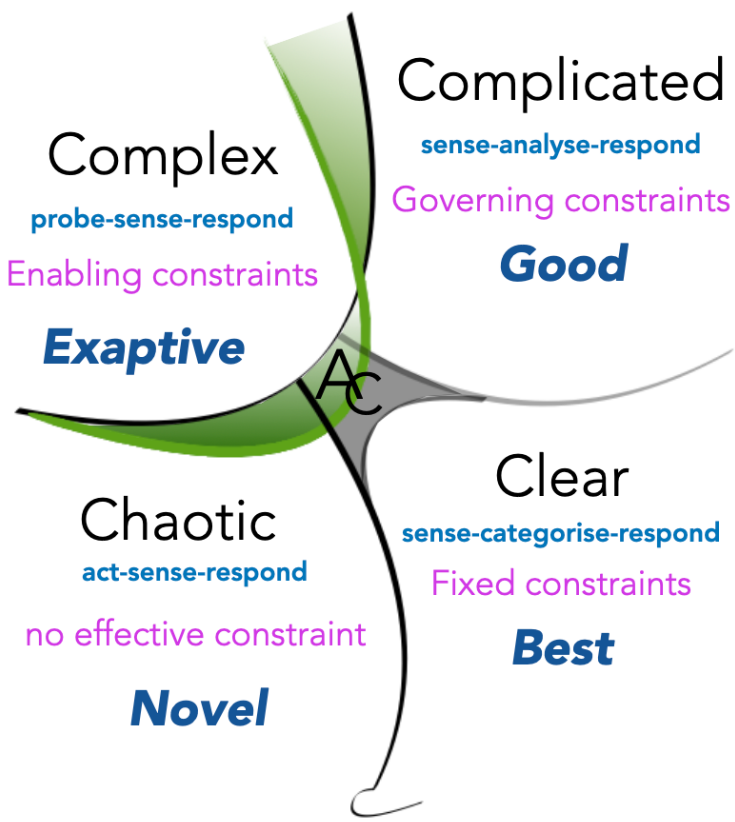
The second model builds on the smart city concept and expands the purpose of collecting information to include making the information available to individuals and organizations so that they can use them for learning and changing their behaviour. They argue that because of the 'rebound effect,' economical, social and ecological sustainability cannot be achieved through efficiency measures alone and that behavioral change of all actors is needed. Therefore, this second model is important for addressing urban sustainability challenges, and Portmann and Finger refer to it as the learning city concept (Finger and Portmann, 2016).

The third model builds on the previous two and involves a new form of intelligence that results from human-machine interaction to come up with creative and disruptive systemic solutions which enable the whole system to adapt to shocks from its environment. This model incorporates a bottom-up approach and is thus more equipped to react and adapt quickly to changes, and address urban resilience challenges. Finger and Portmann refer to this as the cognitive city concept (Finger and Portmann, 2016).

At this point, I would like to draw parallels between the kinds of urban challenges described by Finger and Portmann and context domains in the *Cynefin framework*. The Cynefin framework (Kurtz & Snowdon, 2003) is a sense-making framework used to reach a consensus on decision-making approaches and divides decision-making contexts into four domains based on their degree of order and complexity. The framework proposes a different approach for decision-making under each domain (Kurtz & Snowdon, 2003).

Figure 12

The Cynefin Framework (Snowden, 2021)



In this discussion, two domains from the Cynefin framework stand out the most; the *complicated* domain - sometimes referred as the *knowable* domain - and the *complex* domain. The *complicated* domain includes contexts where cause and effect patterns are stable, repeatable, and known by a board or a limited number of people. In these contexts, analytical and predictive approaches to problem solving work well (Kurtz & Snowden, 2003). For example, the intensity of urban heat islands is impacted by the configuration of buildings, local climate, and materials used in landscaping urban areas, and a predictive model can be built to simulate how these factors impact outdoor thermal comfort in urban areas. Tapias & Schmitt (2014) used such a model to computationally generate design alternatives guided by the predictable relationship between urban form and microclimate (Tapias & Schmitt, 2014). Based on Finger and Portmann's description of the different levels of urban challenges, efficiency challenges fall under this complicated domain.

As for the *complex* domain, it includes contexts where patterns emerge through the interactions of many agents, making cause and effect relationships in this context unpredictable by analytical techniques, and only perceivable retrospectively (Kurtz & Snowden, 2003). Building on the above example of outdoor thermal comfort in urban environments, while controlling thermal comfort impacts how people interact with outdoor spaces, it cannot accurately predict it. Kurtz and Snowdon argue that, in the complex domain, when patterns are analyzed retrospectively to be applied to future situations, these approaches are often confronted by new emerging patterns they were not prepared for. This is because human behavior encompasses multiple dynamic identities and cannot be limited to predetermined rules nor local patterns, making agent-based simulation useful for exploring possibilities rather than decision-making in these contexts (Kurtz & Snowden, 2003). Therefore, the recommended approach to decision-making in the *complex* domain is conducting safe-fail probes, sensing their impact, adopting the ones that succeed, and dampening the ones that fail (CognitiveEdge, 2010). In Finger and Portmann's categorization of urban challenges, sustainability and resilience challenges fall under the complex domain.

In the generative design studies reviewed earlier, the specific objectives these studies have addressed through generative design often fell under the *complicated* domain, such as energy use intensity, natural lighting, solar radiation and shading, topography and water runoff, urban microclimate, and profitability. The human factor was present in some of the studies, such as incorporating preferences of future occupants into the process in Autodesk's new office space (Villaggi et al, 2017), and incorporating predicted traffic patterns in Autodesk University's 2017 Exhibit Hall areas (Nagy et al., 2017b). However, the distinction between the two types of objectives was discussed in terms of their quantifiability in these studies. Nagy et al. classify architectural performance metrics into three groups: those that can be easily quantified and calculated with existing tools, those that can be quantified but would need the development of custom tools to calculate, and those that cannot be quantified. For these objectives that cannot be quantified, such as comfort and beauty, machine learning was suggested as a pathway to quantify and incorporate into the workflow (Nagy et al, 2017a).

I propose that a classification based on *contextual complexity* and the stability and replicability of cause and effect relationships can provide different insights for exploring generative design workflows in complex contexts. To illustrate, the preferences of future users and traffic patterns of people in space are not only more difficult to quantify than solar radiation and energy use, but are also more difficult to definitively predict due to the role of human agency and free will on the outcome. In other words, while the laws and principles of measuring solar radiation do not change from one context to another, human traffic patterns can be predicted based on previous models only to a limited degree of certainty. The practice of considering the human factor in such a context is known as *contextual complexit*y, and it dictates that predictive models should only be used to assist in generating ideas, not for decision-making (Kurtz & Snowdon, 2003).

Urban challenges come in many forms and levels of complexity, and therefore require different approaches to decision-making based on the complexity of the context these challenges occupy. Generative design has an exploratory aspect, i.e. option generation, and a decision-supporting aspect, i.e. evaluating and ranking design options. Building on the parallels drawn between categories of urban challenges - efficiency, sustainability, and resilience - and the Cynefin framework, and the distinction between the two aspects of a generative design process - exploratory and decision-supporting -, we can draw some conclusions on what aspect of a generative design is best used for different urban challenges and different complexity levels.

Table 5

Parallels Between Finger & Portmann's Descriptions of City Paradigms and Urban Challenges, Snowden's Cynefin Framework, and Implications on Generative Design (GD) Use in Divergent and Convergent Design Stages

CITY PARADIGM (Finger & Portmann, 2016)	CHALLENGE CATEGORY (Finger & Portmann, 2016)	DOMAIN (Kurtz and Snowden, 2003)	WHAT STAGE GENERATIVE DESIGN IS BEST USED
Smart City	Efficiency	Complicated	Exploratory + Decision-supporting
Learning City	Sustainability	Complicated + Complex	Exploratory + Decision-supporting
Cognitive City	Resilience	Complex	Exploratory

The third and last observation on generative design that this project addresses is focused on language. A key component of a generative design process is described as navigating tradeoffs between multiple competing objectives or goals, which is inspired by how nature operates (Gerber and Lin, 2014; Nagy et al, 2017a; Nagy et al, 2017b; Nagy et al, 2018; Chang et al, 2019; Walmsley & Villaggi, 2019). Design is conceptualized as a "balancing act between competing objectives all vying for the greatest influence" (Gerber & Lin, 2014, p. 938), hence multi-objective optimization has been explored extensively as an approach to addressing complex design contexts. Genetic algorithms, a type of multi-objective optimization algorithm based on the model of evolution by natural selection, has gained the attention of design computing researchers in the generative design space (Gerber & Lin, 2014). This makes a cohesive narrative of generative design being inspired by nature, and thus could hold the key to addressing the complex issues we face today. However, what this narrative misses is that competition may not be the only driver of evolution.

In nature, competition is not the only driver for the interaction between organisms. Mutualism, where both organisms benefit, altruism, where one organism sacrifices itself for the survival of another, and symbiosis, where unrelated organisms live together, can all be observed in nature (Boggess, 2021). Scientists have proposed new theories for what drives evolution, such as the Biodiversity-related Niches Differentiation Theory that challenges competition as the main driver for evolution (Gatti, 2011). The theory argues that the coexistence of two species can happen only if there is low competition between them, and that avoidance of competition is what drives the expansion of the diversity of organisms (Gatti, 2016). These findings suggest that the current framing of generative design may be missing some key aspects of how nature works, and that there is room for evolving generative design and its terminology to become more aligned with holistic, nature-inspired design processes. This opens up the space for exploring generative design from a new paradigm of cooperation, bridging the gap between generative design as it is known today and regenerative design, which, as Wahl (2016) argues, is rooted in cooperation.

Takeaways: Limitations of Generative Design

In the previous discussions, I have identified three limitations of generative design in architecture and urban planning contexts:

- Generative design is often described as a process of exploring trade-offs between competing objectives which highlights competition as the main driver of evolution. As regenerative design is rooted in cooperation, there is room for a new generative design paradigm that aligns better with environmental sustainability and regeneration.
- Urban challenges are often described as challenges of efficiency, and generative design has often responded to that framing by making multi-objective optimization accessible and applicable across different areas. However, our urban environments are not impacted by efficiency challenges alone; sustainability and resilience are at the forefront of what our cities need to work towards. There is room to explore how generative design can support these goals.
- In generative design workflows, project objectives are often classified based on their quantifiability. Given the complex context of urban challenges, the level of complexity of each objective and the areas it influences could be a more impactful classification, as it would inform how generative design can best be utilized to fulfill each objective, either through exploration of possibilities or assisting in decision-making.

Some of these limitations are conceptual, i.e. related to the initial framing of what generative design is, while others are procedural, i.e. related to how a generative design process is carried out. I suggest that there are opportunities to rethink generative design in a way that addresses these limitations, which I will explore in **Part 4: Generative Design, Where to?**

Part 4:
Generative Design, Where To?

In the previous section, three conceptual and procedural limitations around the application of generative design in urban planning were identified and discussed: the emphasis on competition, efficiencies, and quantification of objectives. In this section, a new generative design paradigm is proposed that addresses the conceptual concerns, and a revised generative design workflow to address the procedural ones.

Contents:

A New Generative Design Paradigm

Process

Constructing an alternative approach for generative design and its application in urban planning contexts is a future-finding exercise of where generative design could go. My purpose of constructing this alternative is to find an alignment between the capabilities that generative design brings and the qualities that make a design process regenerative, and to build a generative design process that supports the resilience and health of the total ecosystem. Numerous methods have been used and developed in the field of strategic foresight for constructing alternative images of the future (Curry & Schultz, 2009). As the project of regeneration is a project of transformation that benefits from the integration of different ways of knowing (Wahl, 2016) a compatible futures method to construct this alternative approach is needed.

Causal Layered Analysis (CLA), a futures research method originally developed by Sohail Inayatullah (1998), enables the framing of contexts and futures from different perspectives by moving up and down the layers of the visible trends, systemic causes, worldviews, and metaphors. This movement results in the integration of different ways of knowing, revealing points of departure from the current state, which can be captured in alternative future scenarios (Inayatullah, 1998; 2014). This framework has been applied in a wide range of topics to lead transformation by deconstructing a current reality or constructing a preferred alternative one, then backcasting to create pathways for achieving that reality (Inayatullah & Milojevic, 2015). The affordances for multi-perspective and multi-layered exploration and transformation makes CLA a suitable approach to deconstruct aspects of current generative design approaches and construct alternatives.

The first step in this process is to deconstruct the current generative design paradigm and its application in architecture and urban planning. This deconstruction is done through the four layers of the CLA framework:

1. The litany: This is the surface-most layer and includes the visible trends and concerns in a given area.
2. Systemic causes: This layer includes social, economic, cultural, and political factors that fuel the litany.
3. Worldview: This layer includes the deeper assumptions behind the issue and systemic causes.
4. Myth/metaphor: This is the deepest layer in the framework and it includes collective stories, archetypes, and unconscious dimensions of the problem.

The second step is to construct an alternative by inflecting the metaphor layer and reinterpreting all layers through this alternative lens.

While this section is focused on presenting a new approach and understanding of generative design, I would like to avoid falling in the trap of perpetuating what is describes as the narrative of "separation into dualistic opposites," which leads to isolation, insufficiency, and competition for domination (Einstein, 2013 as cited in Wahl, 2016, P. 32), and does not align with the purpose of this project. I construct and propose this approach not as a complete negation of the current one, but as an addition to be considered and valued alongside current and other approaches, as a practical exercise of valuing multiple perspectives and ways of knowing and appropriately participating in complexity (Wahl, 2016).

The CLA framework focuses on mapping the internal world and not just the external (Inayatullah & Milojevic, 2015), therefore, the framework brings a lot of personal biases and perspectives, particularly as we go through the deeper layers of the framework. While people might have more shared observations about trends, the systemic causes behind these trends are up to more interpretation, and the perceived worldviews that underlie these systems are even more subjective. At the metaphor layer, even though it refers to collective narratives and stories, the multiplicity of these collective images and the obscure ways they shape our worldviews makes discerning which ones are at play in a particular context highly subjective. Building this model collaboratively would have been the ideal process, but the scope and timeframe of this study have prevented that. I therefore invite you to reflect on the model I propose here and, if you are inclined to, challenge it and reconstruct an alternative direction for generative design based on your own interpretation of what occupies these layers.

Deconstructing the Paradigm

The Litany

The litany is comprised of the three limitations identified around generative design in the previous section:

- **Tradeoffs and competing objectives**: Generative design is a computer-facilitated process of balancing trade-offs between competing objectives.
- **Efficiency and optimization**: Through a generative design process, optimal tradeoffs in a design problem can be found, which helps in addressing complex urban contexts.
- **Quantifying qualitative objectives**: Quantifying qualitative objectives will enable the use of generative design in addressing complex urban contexts.

Systemic Causes: Top-Down Urban Planning

A top-down approach to urban planning seems to underlie the three components of the litany in this model. When decisions impacting the whole system are made by an actor perceived to be outside of that system, it is easy for the interests and needs of those within the system to be seen as mere objectives equally competing for attention. The role of decision makers becomes finding optimal tradeoffs between these objectives. Quantifying these needs and interests makes it easier to objectively decide which tradeoffs are optimal.

Worldview Discourse: Survival, Scarcity, and Control

The drive to compete to gain an advantage and to find tradeoffs between the needs and interests of different groups would not exist in a world of abundance and limitless potential to not only survive, but thrive and flourish. Viewing the world through the lens of scarcity, it is difficult to envision other ways to exist other than striving to survive, and with so many “others” equally striving to survive on little resources, it becomes even more challenging to envision pathways where everyone can access the resources they need; tradeoffs must be made because what is available is only enough for a few, and the sole purpose of everyone is to survive.

In a world of scarcity, resources must be also managed and controlled efficiently. As scarcity leads to competition for resources, wasting, hoarding, or monopolizing vital resources for personal advantage might occur as a way to gain an edge to survive. Controlling access to resources and ensuring the efficiency of distribution and use becomes necessary, and finding objective approaches to measure these aspects facilitates that.

Metaphor: Extinction

The image of extinction is by no means specific to past species. A study of the Earth's biodiversity confirms that there is an ongoing biodiversity crisis, which is probably the beginning of a Sixth Mass Extinction threatening most of Earth's biodiversity as we know it (Cowie et al, 2022). Karl Albrecht considers the fear of extension to be at the base of the "feararchy" of the five fears all humans share (Albrecht, 2012).

I am interpreting that at the metaphor layer, extinction is one of the images that underlie the worldviews, systems, and trends previously discussed. Fear of extinction justifies the evolution of a worldview that considers competition a pathway to ensure the physical survival of some of its members to keep the presence of the species. Without fear of extinction, alternative worldviews could evolve that value the flourishing of all members of a species equally.

Constructing a New Paradigm

Metaphor: Perpetuity

Extinction has a strong presence in our collective knowledge, but it is not the only image we have, and finding alternative metaphors to build on is the starting point for constructing a new paradigm from the ground up.

The concept of perpetuity is present in different traditions and languages. In traditional Islamic texts, the transience of the "closer" life is often contrasted with the permanence of the "later" life (life after death), hence there is a sense of perpetuity to the impact one has in their lifetime. Dianne M. Longboat describes the Anishinaabe perspective on life and death, as people being spirits "having a human experience." The spirit leaves the spirit world upon birth, and returns back to that world upon death. In other words, the spirit lives forever (Longboat, 2002, p. 6). The fact that language has so many affordances to describe the state of endlessness indicates that the idea of perpetuity is as present for the collective, regardless of tradition and belief system, as is extinction. Feeling connected and part of something that lives on provides us a sense of psychological safety in the face of mortality, which drives us to work towards leaving a lasting legacy (Wade-Benzoni et al, 2012).

While physical extinction will still have a strong presence in our collective knowledge, **what would a worldview look like if all of the impact our civilization had on Earth, and beyond Earth, both tangible and intangible, is kept in perpetuity? And what would it look like if the quality of that impact is as important as our physical survival?**

Worldview Discourse: Flourishing, Abundance, and Appropriate Participation

The drive to physical survival would be accompanied by the drive to make the story of that survival one we can be proud of. In the Altruistic Brain, Pfaff establishes that we are "wired" to behave altruistically, and that spontaneous kindness is our default behavior regardless of religious or cultural determinants (Pfaff, 2015). It is therefore only natural that we would want the story of our survival to be representative of that altruistic nature as well. Survival of the few for the sake of the survival of the species would not be enough; flourishing together would be just as important as the survival of the species.

This shift from mere surviving to surviving for collective thriving and flourishing is aligned with what Charles Eisenstein describes as the shift from the “story of separation” that breads competition to the “story of interbeing” which recognizes our relational and interdependent nature (Eisenstein, 2013, P.15). It is a shift from a narrative that places us outside of the ecosystem to a narrative that recognizes that we are part of it. Control and prediction are part of the story of separation, as being part of a complex system makes the attempt to control it obsolete. As Brian Goodwin argues, our attitude within a complex adaptive system should be that of “appropriate participation” by understanding the dynamics of the system to facilitate positive emergence (Goodwin, as cited in Wahl, 2016).

The two shifts discussed above create a shift in our relationship with the availability of resources and reinforces this shift through a positive feedback loop. To be open to the possibility for the total ecosystem to flourish collectively, we must start seeing abundance in place of scarcity, and by recognizing our role as appropriate participants in the ecosystem, we recognize that it is our role to co-create abundance, which in turn creates the abundance needed for total flourishing. Wahl describes this shift in Designing Regenerative Culture as “win-win-win” cultures for the individual, collective, and the planet, where shared abundance is created through collaborative advantage (Wahl, 2016).

Systemic Causes: Bottom-Up & Top-Down Urban Planning

In discussing the different approaches to the integration of information and communication technologies into urban environments to address urban efficiency, sustainability, and resilience challenges, Finger and Portman establish how a bottom-up approach that enables actors to align practice with the changing knowledge context is built upon a top-down approach that collects information to better manage and optimize infrastructure systems. (Finger and Portmann, 2016). A combined system of top-down and bottom-up planning aligns well with the attitude of appropriate participation in the ecosystem.

The Litany

Having gone through the deeper layers of the current paradigm and having reconstructed these layers based on a different metaphor and worldview, it is possible to envision an alternative discourse that addresses the three concerns around generative design that were identified in Part 2:

- **Synergies**: Generative design is a computer-facilitated process of exploring synergies between seemingly irreconcilable objectives.
- **Resilience**: Enabling all stakeholders in a design context to explore synergies through a generative design process can contribute to fostering resilience in complex urban contexts.
- **Emergence**: Generative design can help in exploring novel ideas to fulfill complex objectives, leaving room for emergence in these contexts.

Figure 13

Deconstructing the Current Grenerative Design Paradigm through a Causal Layered Analysis Framework

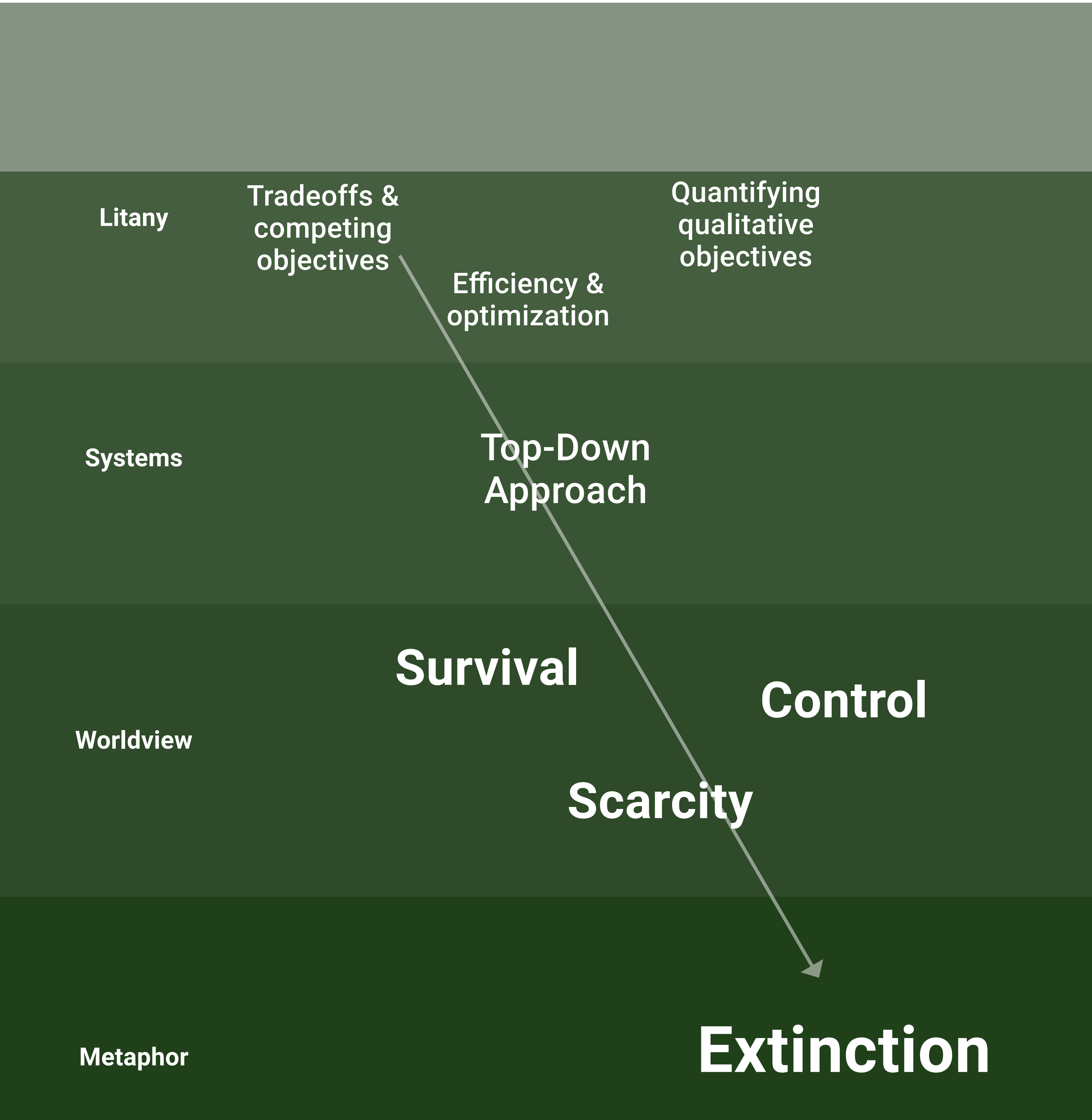
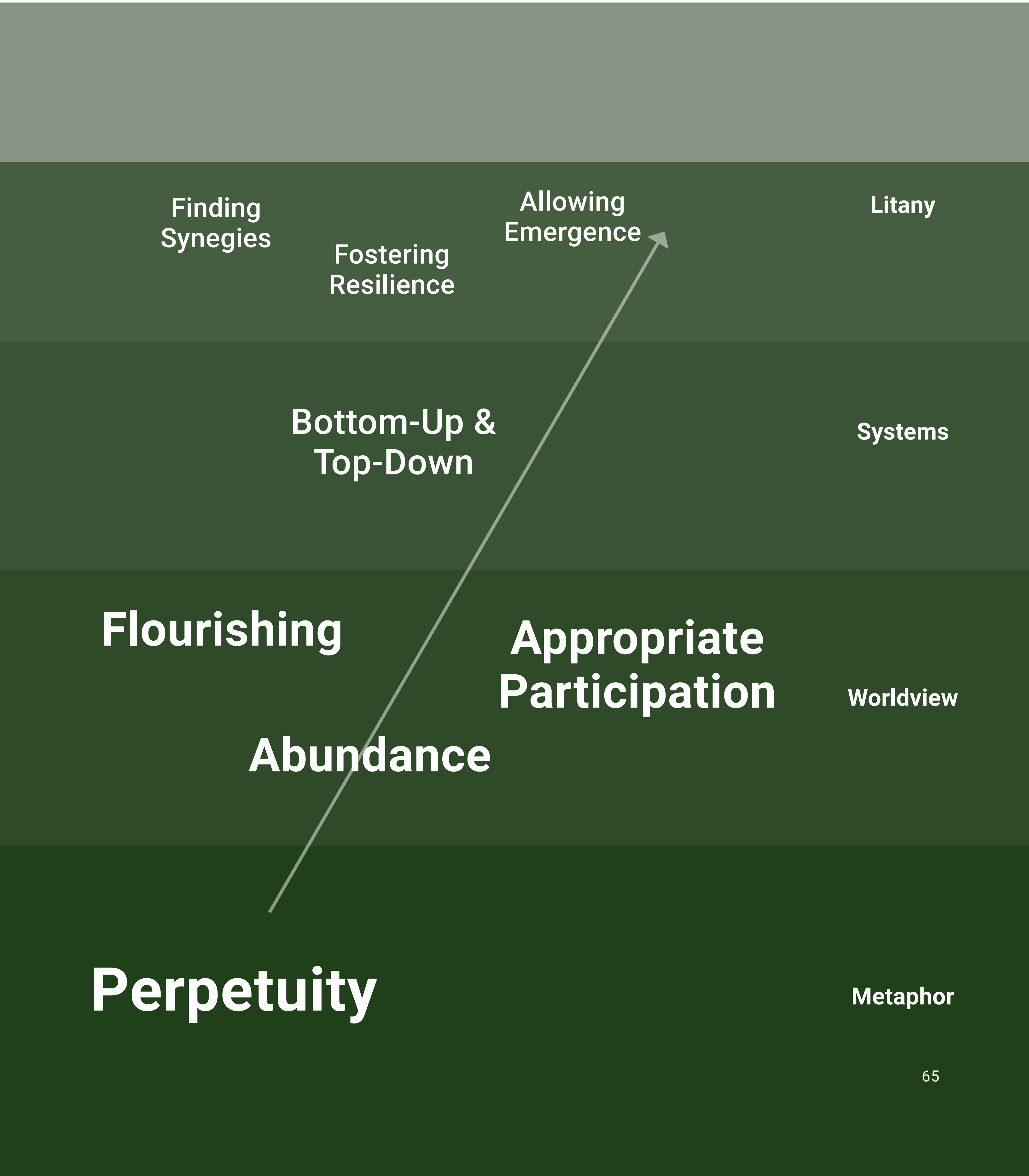


Figure 14

Constructing a New Generative Design Paradigm through a Causal Layered Analysis Framework



Takeaways: Implications of a New Paradigm

Language: Synergies and Apparent Incompatibility

The first implication of this alternative paradigm is the need to rethink some of the terminology used in describing the generative design process and the advantages it has over conventional processes.

In Designing Regenerative Cultures, Wahl establishes that in a regenerative system, groups and individuals meet their needs by connecting previously competing participants synergistically, in other words, by connecting unmet needs with new capacities, leading to non-zero sum relationships. Strengthening these collaborative networks is what builds the resilience of the system to weather disruptive events (Wahl, 2016). To explore generative design from a worldview that sees the possibility of win-win-win cultures existing and replacing win-lose cultures, we could start thinking of generative design as a process of ‘exploring synergies’, not only a balancing of trade-offs.

This also strongly suggests the need to explore generative design from a worldview that recognizes that competition is only one of the ways organisms relate to one another. We can do this by describing the relationship between design objectives through their ‘apparent’ incompatibility, rather than assigning a state of competition amongst them. By changing the way we talk about objectives, we emphasize that while some objectives might be indeed incompatible, it is also possible that other objectives can be reconciled even though they seem incompatible at first sight. This leaves the door open to finding synergies and understanding that the needs of different actors within an ecosystem do not have to be in constant competition.

Establishing new terms to describe generative design may or may not change the technicality of how the tools work, but it would more likely change the way we see and navigate complexity. This change is key to transitioning to a regenerative design approach.

Attention: Soft Generative Design

A technically successful generative design process results in highly optimized solutions that are needed to address efficiency challenges. However, the collaboration that occurs between human designers throughout a generative design process can have far-reaching impacts beyond efficiencies. As established earlier, regenerative cultures are rooted in collaboration, and collaborative networks are what builds a system's resilience. A generative design process can be designed to offer a space for participants in an ecosystem to collaboratively create a design concept, define goals, objectives, and metrics, build the generative model, and explore solutions and synergies. A learning and adaptable ecosystem can emerge through this collaboration, which is essential to fostering resilience in complex urban contexts. Moreover, the nature of the collaboration between human designers is key in addressing potential incompatibility between design objectives when synergies are not found, in both cases of building design objectives as metrics into the generative design model, or evaluating objectives outside of the model.

Could we see and value the collaborative aspects of a generative design process, just as we value the technology that supports the process? Christopher Alexander's generative codes highlight these humanistic qualities in procurement processes as core to the generative code: " a long chain of human events, involving respect for people, respect for one another, respect for land and place.... Above all it comes from the land, and it comes from the people" (Alexander et al, 2005, p. 2). A generative design process that supports a system's regeneration and resilience is therefore a collaborative process where all groups impacted by the design outcome are involved and respected in the process.

Table 6

Parallels Between Finger & Portmann's Descriptions of City Paradigms and Urban Challenges, Snowden's Cynefin Framework, and How Generative Design (GD) is Best Used to Support Each Paradigm and Address Challenges

CITY PARADIGM (Finger & Portmann, 2016)	CHALLENGE CATEGORY (Finger & Portmann, 2016)	DOMAIN (Kurtz and Snowden, 2003)	HOW GENERATIVE DESIGN IS BEST USED
Smart City	Efficiency	Complicated	Running optimization studies
Learning City	Sustainability	Complicated + Complex	Sharing the process with participants
Cognitive City	Resilience	Complex	Collaboratively building the process

Taxonomy: Contextual Complexity

In a generative design process, the nature of design objectives informs how generative design can best be used to fulfill these objectives. I suggest the following taxonomy to differentiate the kinds of objectives that designers aim to fulfill:

1. **Low contextual complexity**

These are objectives where human agency has little to no impact on whether a solution fulfills the intended objective. Examples of these are: maximizing the amount of solar radiation a plot of land receives, minimizing the surface area of a building's envelope, and minimizing the distance between destinations.

2. **High contextual complexity**

These are objectives where human agency has a significant impact on whether a solution fulfills the objective or not. Examples of these objectives are: improving social cohesion within a neighbourhood, improving walkability, and improving perception of safety.

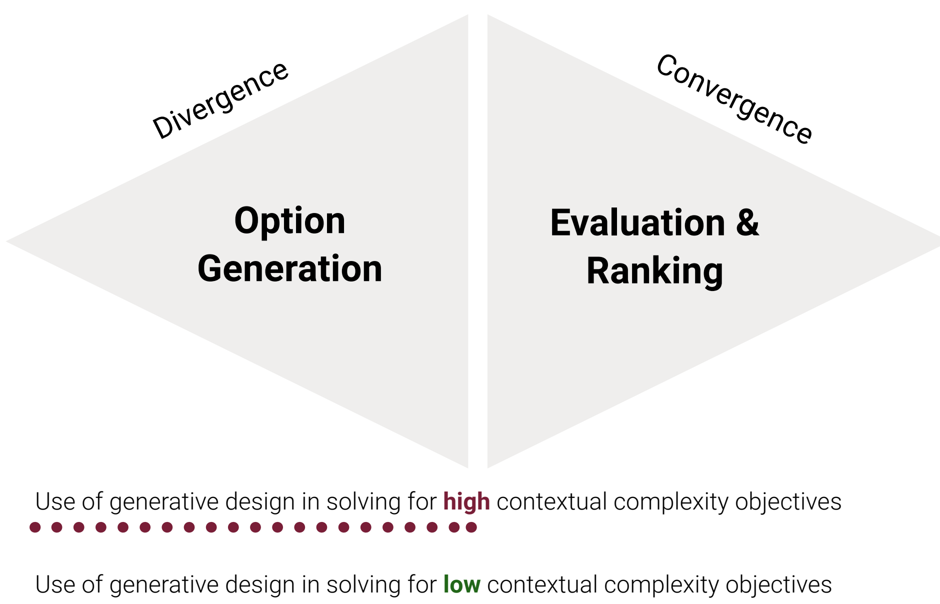
Generative design is most effective in generating solutions that succeed in fulfilling objectives with low contextual complexity. It is also highly effective in ranking these solutions based on their performance. In other words, both divergent (explorative) and convergent (decision-supporting) stages of a design process can benefit from generative design in problems of low contextual complexity.

When it comes to objectives with high contextual complexity, I suggest that ranking the success of solutions in meeting these objectives using metrics built into the generative design model must be understood as only speculative, not as a main driver for selecting solutions and making decisions. In other words, divergent stages in a design process benefit from generative design the most in high contextual complexity. In convergent stages of a design process, ranking of solutions through generative design is better contested and challenged by the collective judgment of the team.

Objectives under the category of high contextual complexity can be thought of as emergent properties, and thus, they cannot be controlled nor predicted. In exploring the relationship between design, emergence, and innovation, Van Alstyne and Logan establish that emergence is nature's way of design, and that nature "does not control; she merely accepts whatever is the best fit" (Van Alstyne & Logan, 2007, p. 128). If generative design is indeed inspired by nature, some objectives may be better left to emerge.

Figure 15

Implications of a New Generative Design Paradigm on Taxonomy of Design Objectives



A Revised Generative Design Workflow

In this section, I propose a revised generative design workflow with the aim that this workflow accounts for the complexity of the design context and aligns with sustainability and regenerative design goals. The workflow is informed by the generative design paradigm presented in the previous section, Peter Jones' Systemic Design Principles for Complex Social Systems (Jones, 2014), Christopher Alexander's Generative Codes (Alexander et al, 2005), and Daniel Wahl's Designing Regenerative Cultures (Wahl, 2016).

To expand design practice to higher levels of complexity, Peter Jones proposes a set of crossover principles between systems and design theory, as the two systems of thought aim to enable "appropriate, organized high-leverage action in the increasingly complex and systemic problems as design situations" (Jones, 2014).

These principles are:

- Idealization
- Wickedness
- Purpose
- Boundary framing
- Requisite variety
- Feedback coordination
- Ordering
- Generative emergence
- Continuous adaptation
- Self-organizing

Cities are highly complex socio-techno-ecological systems. Designing for urban environments involves all four domains that Jones and Van Patter (2009) identify:

- **Design 1.0 traditional design**

Designing urban environments involves designing artifacts and communications, such as buildings, streets, signage, and pathfinding. In a generative design process, visualization of design solutions is part of this design domain.

- **Design 2.0 product/service design**

Products and services are circulated and offered through built environments. Design is a service, so a generative design process and how it is carried out is part of this design domain

- **Design 3.0 organizational transformation design**

Organizations and institutions are part of urban environments, and they shape and are shaped by them. A generative design process cannot be carried out outside of these organizations, who in their part also influence and are influenced by the process.

- **Design 4.0 social transformation design**

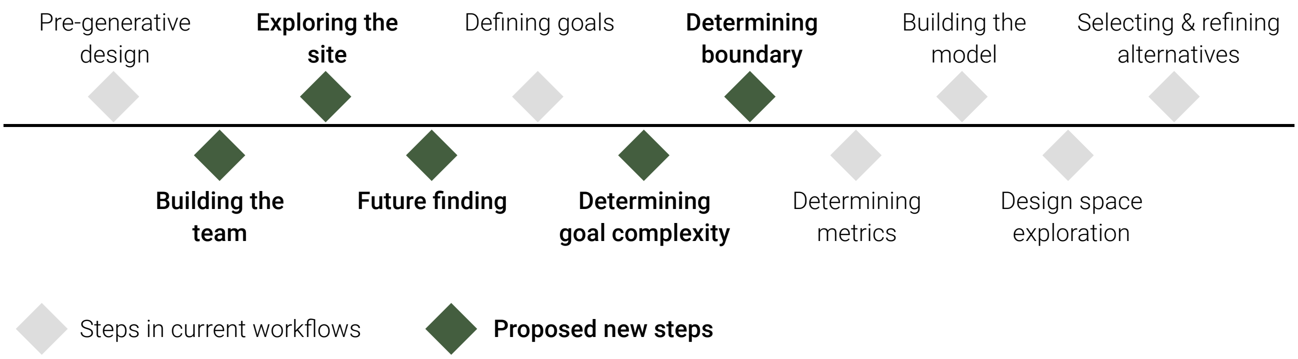
The social and cultural fabric underlies urban environments, and efforts to build resilience and regeneration into urban environments aim to create social transformation. A generative design process that builds on collaboration is a process of social transformation.

Therefore, building on the ten principles could provide insights into establishing a generative design process that addresses complexity of design contexts. As a reference workflow, I have used the generative design workflow summarized in Part 2 section 3, Workflow, which was based on the new Autodesk office space in Toronto (Nagy et al, 2017a), Autodesk University conference hall in Las Vegas (Nagy & Villaggi, 2020), and a residential neighbourhood development project in Alkmaar, Netherlands (Nagy et al, 2018). I also build on my own experience working on the project summarized in Part 2 section 4, Generative Design in Practice. This section summarizes the reference and revised workflow, and expands on the steps introduced in the revised workflow and the rationale behind them.

Revised Workflow

Figure 16

Revised Generative Design Workflow



Building the Team

I have established that for a generative design process to support a community's regeneration and resilience, it needs to be a highly collaborative process where all groups impacted by the design outcome are involved in the process. To address this in generative design, the process starts with determining all stakeholders impacted by the project, and involving representatives of all stakeholder groups as team members to consult and work with to explore synergies between objectives.

The principle of requisite variety supports this step. The law of requisite variety indicates that for a dialogue to be effective and lead to transformative interventions in a given problem context, variety among stakeholders in the dialogue must account for variety in the social system that makes up the context of the problem (Christakis, 2006, as cited in Jones, 2014). Therefore, for generative design collaboration to be effective in addressing complex design contexts, variety among team members must match that of the stakeholders impacted by that context.

Exploring the Site

This step is informed by Christopher Alexander's Generative Codes. Building on his previous work in A Pattern Language, Alexander et al. (2005) argue that the process of building welcoming, beautiful, and sustainable neighbourhoods is a process that binds land and people together into a "social-spatial tapestry". They propose a generative code that, rather than form-based, is procurement process-based. This code states that, a genuine satisfaction with a neighbourhood requires that the users must physically play a role in laying out the space, and that it makes a difference when people do that exercise on the ground by "walking around together on the land itself, placing strings, stakes, and markers, and reaching a state, in their minds, where they almost feel that the buildings are already there" (Alexander et al., 2005, p. 10)

In a generative design process, the team must then explore the physical site together. While in computational generative design designers do not fully create the layout of a space, they can still think through the geometry generator concept and develop it in the physical site before building it on the computer. This step aims to mitigate the disconnect between land and people which occurs when drawings are the only medium where a design is explored and developed. Maintaining a direct connection with the site is even more important when computers are tasked with generating the geometry of the design. I would argue that even if strings, stakes, and markers are replaced with other advanced tools when developing the concept, being physically present on site is what helps maintain that connection to a large extent.

Future Finding

This step is informed by the principle of idealization, which refers to the identification of an ideal state that drives action towards an outcome (Jones, 2014). This is also aligned with The Natural Step framework, which is a science-based practical framework designed to guide actions and behaviours towards achieving sustainability. The first step in The Natural Step's ABCD process is awareness, and it is about building a vision of what success looks like in a sustainable future (The Natural Step, 2008).

In a generative design process, this step involves collectively constructing images of desired alternative future/s, or scenarios, through foresight work. Methods such as Causal Layered Analysis (Inayatullah, 1998), Three Horizons (Sharpe et al., 2016), and the Manoa Futures Wheels (Schultz, 2015), are some of the methods that can be used to construct these scenarios.

Backcasting scenario building frameworks, such as Three Horizons, can be particularly useful in this step. This framework is based on three patterns: the first horizon represents the established pattern which gives way over time to an emerging third horizon, and a second horizon facilitates that transition (Sharpe et al, 2016). Causal Layered Analysis (CLA) enables the integration of different ways of knowing into the scenario building method by moving through the layers of litany, systemic causes, worldviews, and metaphors (Inayatullah, 1998; 2014). CLA is described in detail in the previous section: **A New Generative Design Paradigm**, where it was used to construct an alternative approach to generative design.

Part 5: Generative Design and Foresight elaborates on this step of future finding within a generative design process. The Manoa Futures Wheels method is used to explore the futures of neighbourhoods and communities in the Greater Toronto and Hamilton Area. Three divergent scenarios are created and a number of design objectives are proposed based on these scenarios.

Determining Goal Complexity

This step is informed by the earlier discussion about an alternative generative design paradigm, in addition to the principle of Appreciating Wickedness, as wickedness is normally used as a reference for high complexity (Jones, 2014). I propose the addition of this step as a way to address complexity in the problem space. As discussed under the new generative design paradigm, the nature of design objectives informs how generative design can best be used to fulfill these objectives. In that discussion, I proposed the following taxonomy to differentiate the kinds of objectives that might come up in a generative design process - a more complete discussion of this taxonomy is presented under Takeaways: Implications of a New Paradigm in Part 4:

- **Low contextual complexity**

These are objectives where human agency has little to no impact on whether a solution fulfills the intended objective.

- **High contextual complexity**

These are objectives where human agency has a significant impact on whether a solution fulfills the objective or not.

The scope of this report focuses on contextual complexity as described by Kurtz and Snowden (2003). However, outside of that scope, other forms of complex objectives could be treated similarly if cause and effect relationships are only discernible in retrospect.

Determining Boundary

Once the complexity of each goal is determined, the boundary of the generative design model and how it will be used in guiding decision-making must be determined. This boundary takes shape in the two steps of **determining metrics** and **selecting and refining alternatives**.

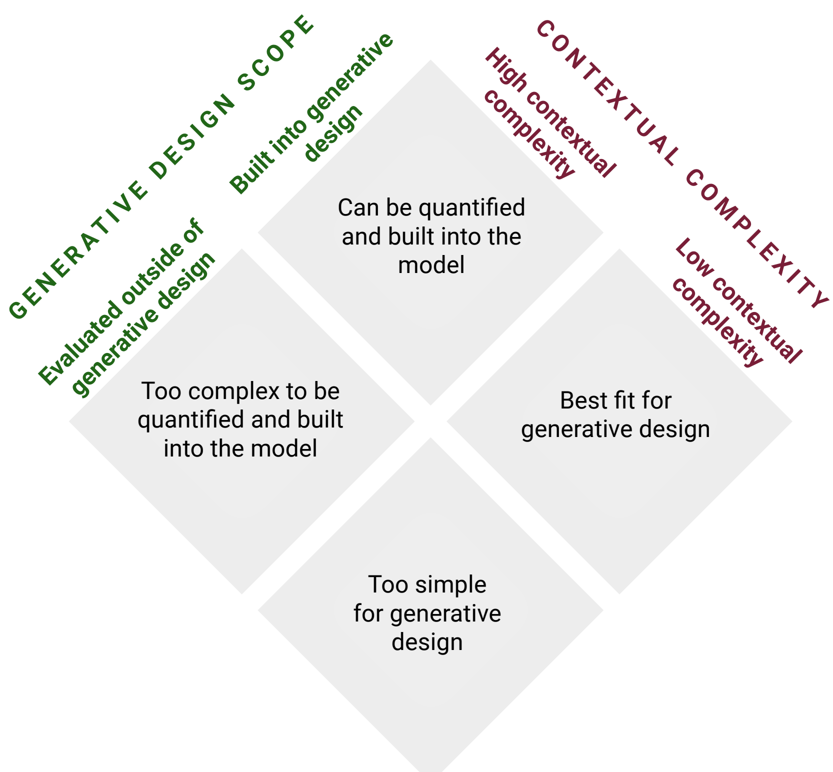
1. **Determining metrics**

- For objectives with low contextual complexity, building quantitative metrics into the model is relatively straightforward, tools might be available to measure these objectives, or designers can build metrics using available tools. There are cases where these objectives are simple and that they can easily be evaluated outside of the generative design model.
- For objectives with high contextual complexity, the team must determine whether they will translate these objectives into metrics in the model, or if they will evaluate these objectives outside of the generative design model.

This boundary framing results in dividing project objectives into four groups shown in Figure 17.

Figure 17

Types of Design Objectives Based on Contextual Complexity and the Scope of a Generative Design Process



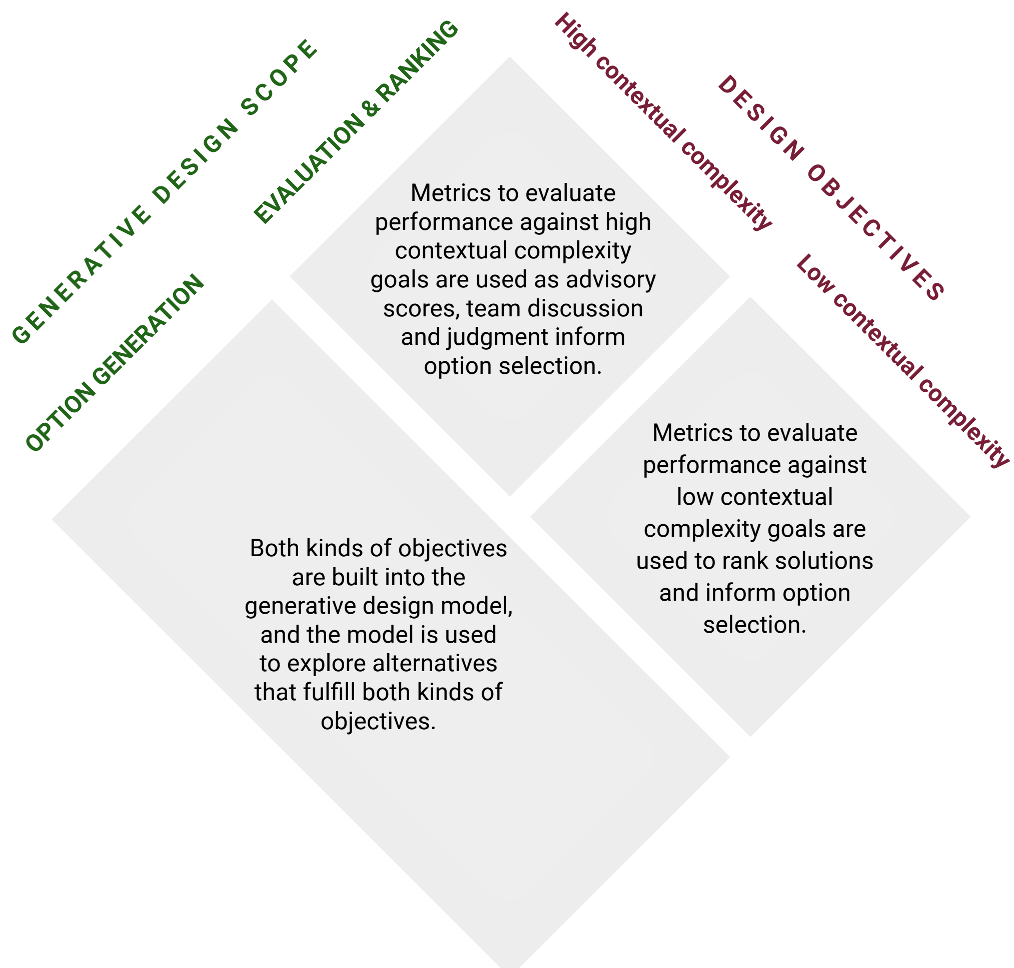
2. **Selecting and refining alternatives**

Metrics that evaluate solutions against goals with low contextual complexity are used to rank solutions and inform option selection.

Metrics that evaluate solutions against goals with high contextual complexity are used as advisory scores, option selection must be informed by team discussion and judgment. The aim is to exert less control and allow space for generative emergence.

Figure 18

Scope of Generative Design Based on Design Objectives Complexity



Takeaways: Re-generating Generative Design

Approaching generating design from a complexity lens and incorporating systemic design principles into the process is needed as our urban environments are highly complex socio-techno-ecological systems. Based on insights from systemic design and regenerative design, I have proposed a number of additional steps into the existing generative design workflows.

For a generative design process to support the regeneration and resilience of a community, I propose that it must be a highly collaborative process where all groups impacted by the design outcome are involved in the process as team members. Variety among team members must match the variety of the stakeholders impacted by the project.

I then propose that the team must explore the physical site and develop the concept for the geometry generator while in the physical site. Maintaining a connection with the site is important in any design process, but it is even more important when computers are tasked with generating the geometry of the solution.

Collectively constructing images of desired alternative futures through foresight work helps align the team around a future vision and informs defining project objectives. The complexity of these objectives must then be determined as that informs how generative design can best be used to fulfill these objectives.

Objectives with low contextual complexity are relatively simple to build into the model, and generative design can be used to rank solutions against them to inform option selection. On another hand, objectives under the category of high contextual complexity are emergent properties, and thus by nature, they cannot be controlled nor predicted. I suggest that the metrics used to evaluate these objectives be used as advisory scores, leaving room for emergence.

Part 5:
Generative Design and Foresight

One of the propositions of the previous section was that building shared images of desired futures through foresight work can help align the design team around a future vision and inform project objectives in a generative design process. This section elaborates on the step of future finding in the revised generative design process presented in the previous section. Here, we look at the futures of communities and neighbourhoods in the Greater Toronto and Hamilton Areas (GTHA), as an example foresight process that was facilitated with a generative design project team designing alternative layouts for a new neighbourhood project in the City of Brampton. The foresight process resulted in a number of future scenarios that informed the development of design objectives to evaluate the neighborhood alternative layouts.

Contents:

Future Finding in a Generative Design Process

In the previous section, I have proposed a revised generative design workflow that aims to address complexity in a generative design project and support the regeneration of the system. Future finding is introduced as a step where images of desired alternative futures, or scenarios, are collectively constructed through foresight work. This participatory process contributes to building collaboration into the workflow and creating a vision for what the project must achieve to support the health of the system. The generated scenarios would inform the next steps in a generative design workflow, such as defining objectives and metrics.

In the following account, I describe a participatory foresight process I facilitated with a generative design team working on designing alternative layouts for a neighbourhood in the city of Brampton. The neighbourhood is being designed as a new development, so the particular community that would inhabit it in the future is not yet identified. Future inhabitants could be residents from the city of Brampton, and they could also be new to the Greater Toronto and Hamilton Area (GTHA). To maintain a level of localism in the scenarios generated while avoiding biasing the scenarios towards residents of Brampton specifically, I chose the GTHA as the scale at which scenarios will be generated.

I start by explaining the theoretical grounding of the foresight process, then describe the process which consists of two main parts: a horizon scan and a foresight workshop. I then present the scenarios generated, followed by a synthesis of these scenarios into design objectives.

Foresight Process

Neighbourhoods are influenced and shaped by social, technological, economic, environmental, and political forces at play on the local, regional, and global scales. Neighbourhoods, like cities, are complex socio-technical systems that adapt and evolve as a response to these conditions. To construct divergent images of the futures of neighbourhoods, a method that builds on multiple drivers of change and how these drivers interact to generate divergent outcomes.

The Manoa Futures Wheels is a scenario building method developed by Wendy Schultz (2015) as a method that is participatory, maps the steps of divergence from the present, includes multiple drivers of change, and results in different outcomes with a long time horizon (Curry & Schultz, 2009). The Futures Wheels resemblance to complex adaptive systems and their response to chaos (Curry and Schultz, 2009) and its resemblance to generative design in its ability to generate a large number of scenarios informed the choice of scenario building method for the futures of neighbourhoods.

I started this process with a horizon scan of trends, emerging issues, and weak signals, which I synthesized into a set of seeds of change. I then planned and facilitated a series of workshops where participants built scenarios based on the impacts and cross impacts of different seeds of change. The series of workshops resulted in three future scenarios that were synthesized and shared back with the team.

Horizon Scan

Emerging issues and weak signals are described as the preferred starting point for building the scenarios in the Futures Wheels method, but the literature is not as prescriptive and sometimes refers to drivers of change or trends forming the basis of each scenario. (Curry & Schultz, 2009; Schultz, 2015). Our team was interested in exploring scenarios based on widespread trends as well as exploring unexpected ones. Therefore, the horizon scan covered indicators of change, regardless of their maturity or impact level in the present. The Manoa Futures Wheels method specifies that the three signals used to build each scenario must come from a different STEEP sector (Schultz, 2015). The horizon scan therefore covered a wide range of signals from all STEEP-V (social, technological, environmental, economic, political, and values) sectors.

The guiding question for the horizon scan was “what is changing in neighbourhoods and communities in the GTHA?”. News articles, team members, and existing formal and informal foresight work were consulted to inform the horizon scan such as:

- ARUP’s Drivers of Change (ARUP, 2018)
- Dufva and Rowley’s Weak Signals 2022: Stories about Futures (Dufva & Rowley, 2022)
- The Future of Urban Tech by the Jacobs Institute’s Urban Tech Hub (Michael Samuelian et al., 2021)
- Twitter posts that answer questions similar to the guiding question, e.g. “Finish this sentence: “In the next 5-10 years, cities will…” (Toderian, 2022)

Signals were collected and synthesized into Seeds of Change, which encompassed emerging issues and mature trends. I posted the Seeds of Change cards on a Miro board which team members could access and add comments to.

Foresight Workshop

Pre-Workshop

The workshop was planned to be delivered over three sessions. In each session, six to eight participants would develop one scenario based on three seeds of change. Experts from architecture, urban planning, data science, political science, business consultation, design, and foresight, in addition to non-expert participants residing in the GTHA were invited to participate in the workshop.

A short survey was sent to participants prior to the workshop which was part of the horizon scan described earlier. Participants were also provided with a link to access the digital board that had a summary of the seeds of change.

Workshop Delivery

Workshop sessions were delivered remotely over Microsoft Teams and Miro, each session running for 90 minutes. Four to ten participants joined each session remotely and the sessions were recorded and transcribed using Teams.

Each session started with a brief introduction to participatory foresight and the scenario building approach that will be used. Participants were asked to introduce themselves and, using one word, to describe the future of neighbourhoods in their opinion.

A brief overview of the seeds of change was presented, and participants were asked to select the top three seeds they are interested in building the scenario around. Each participant voted for three seeds, and the three seeds that received the highest votes were selected for the scenario. To ensure that the scenarios were divergent, participants had to select seeds of change that were different from the ones already used in the previous sessions.

Participants were then given access to a Miro board that was prepared prior to the workshop. The process of creating the future wheels is described below. The Futures Wheels created in each session are included in Appendix B.

The Futures Wheels - Version 1

In the first session, the approach outlined by Schultz (2015) was followed to build up the future wheels (Schultz, 2015). A future wheel was created for each seed of change by identifying the impacts of each seed separately, then discussing the cross impacts of these seeds together (Figures 18 and 19). This approach was challenging in remote workshop format as computer screens are not large enough to display all three wheels together, making it difficult to connect impacts across wheels.

The Futures Wheels - Version 2

In the second and third sessions, the approach was adapted for remote delivery and the limited time allocated for each session. As participants had to view the futures wheels on computer screens, the three wheels in each workshop session needed to be viewed simultaneously to facilitate creating connections between the impacts of each seed. Therefore, the impacts of the three seeds of change were recorded in three concentric circles around one wheel over four steps:

1. The first seed of change was added to the centre of the wheel, and participants discussed the impacts of that seed over the next 10 years and recorded their notes in the first ring closest to the centre (Figure 20).
2. The second seed of change was added to the centre, and participants discussed the impacts of that seed, combined with the first seed, over the next 20 years. Impacts were recorded in the second ring (Figure 21).
3. The third seed of change was added to the centre, and participants discussed the impacts of that seed, combined with the first two seeds, over the next 30 years and recorded their notes in the third ring (Figure 22).
4. Additional secondary impacts were discussed and recorded in the outermost ring and the scenario was named (Figure 23).

Figure 19

Futures Wheels 1.0, Participants Identify the Impacts of Each Seed of Change Separately: 'Growing Density & Diversity,' 'Hybrid Work,' and 'Electrifying Transportation'. Then, They Explore the Cross Implications of These Impacts

Figure 20

A Close-up of One of the Futures Wheels 1.0

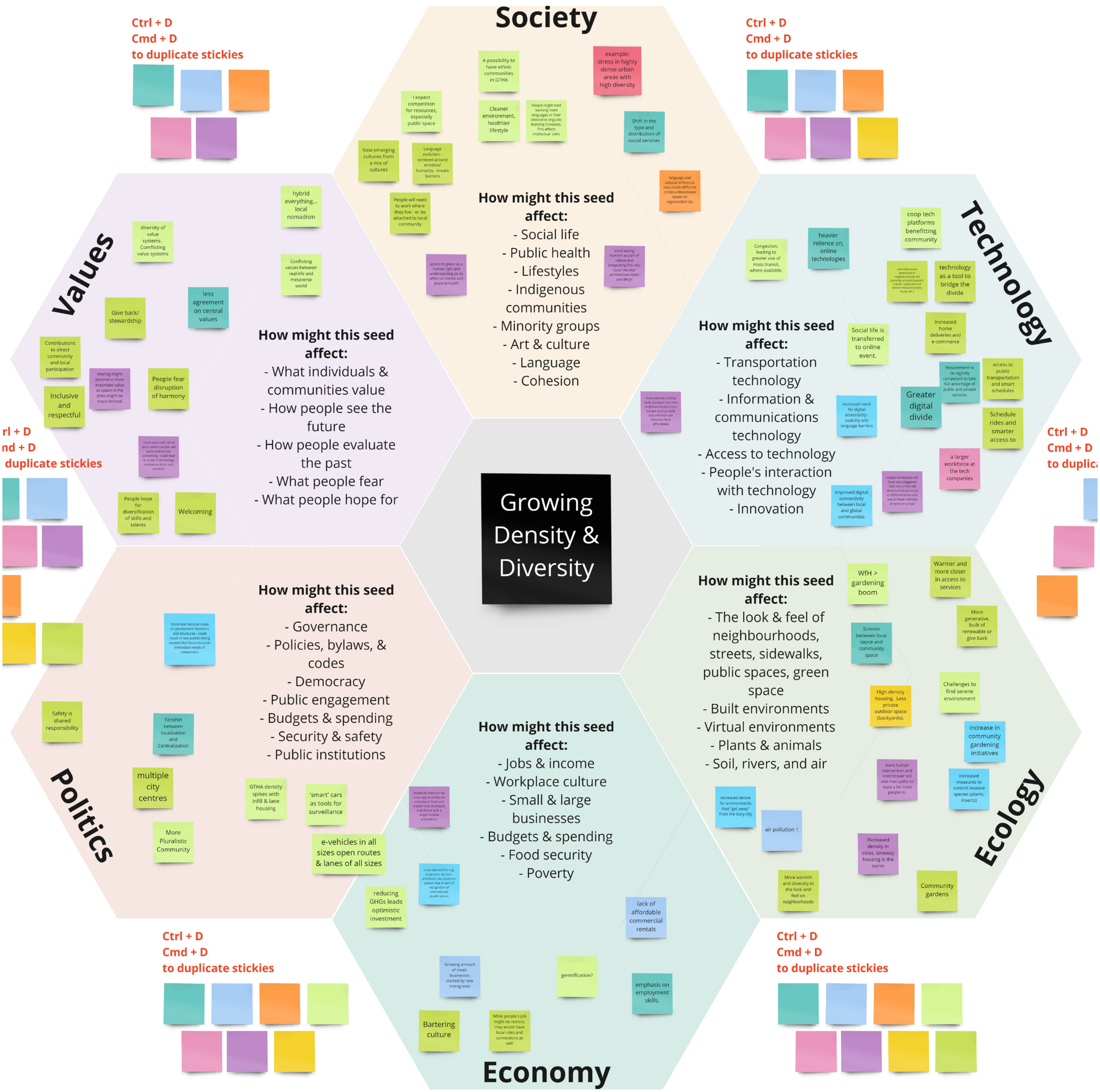


Figure 21

Futures Wheels 2.0, Participants Identify Impacts of the 1st Seed of Change 'Diminishing Affordability'

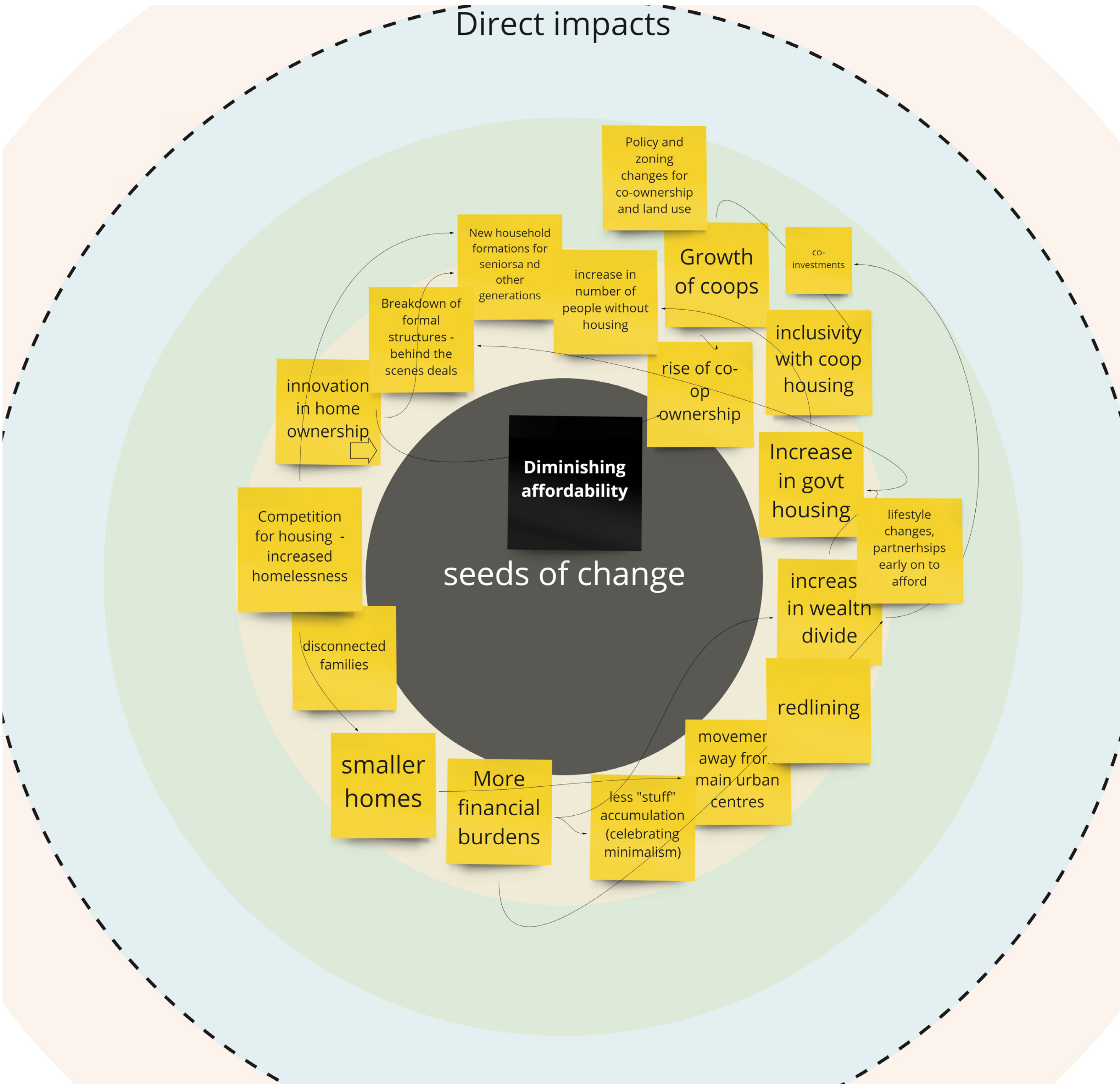


Figure 22

Futures Wheels 2.0, Participants Identify Impacts of the 1st and 2nd Seeds of Change 'Diminishing Affordability' + 'Redefining the Household'

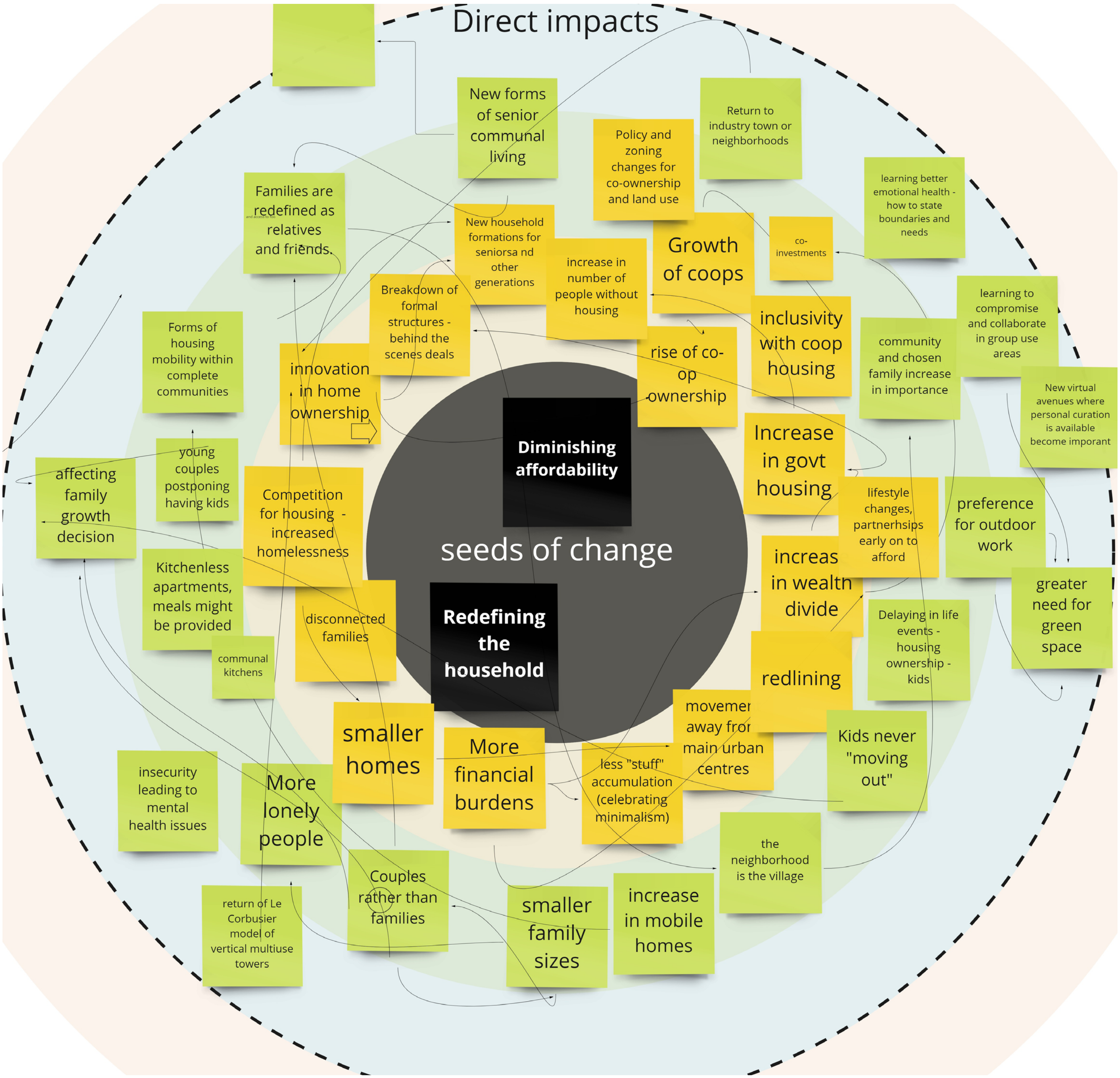


Figure 23

Futures Wheels 2.0, Participants Identify Impacts of the 1st, 2nd, and 3rd Seeds of Change 'Diminishing Affordability' + 'Redefining the Household' + 'Extreme Weather Conditions'

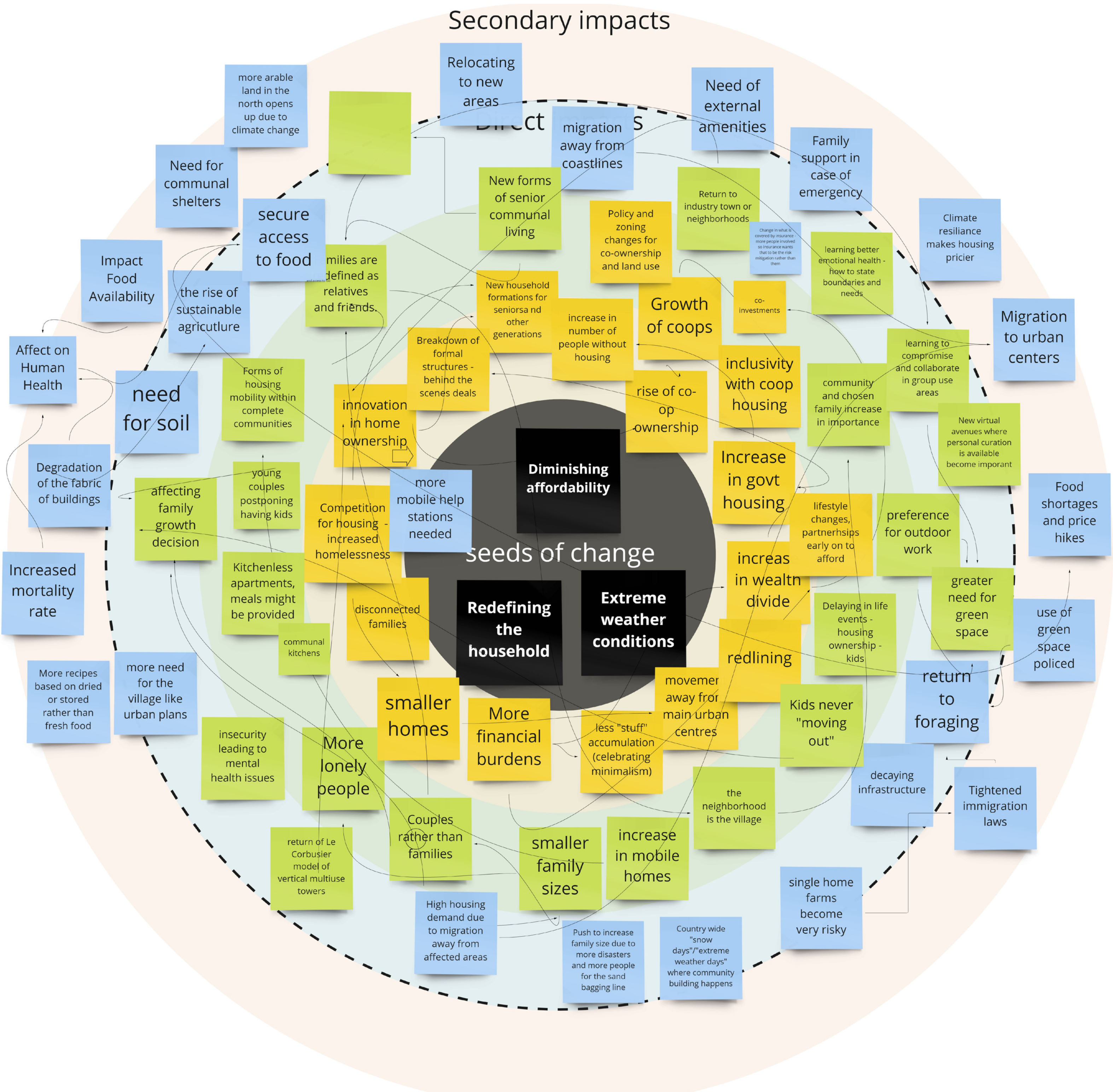
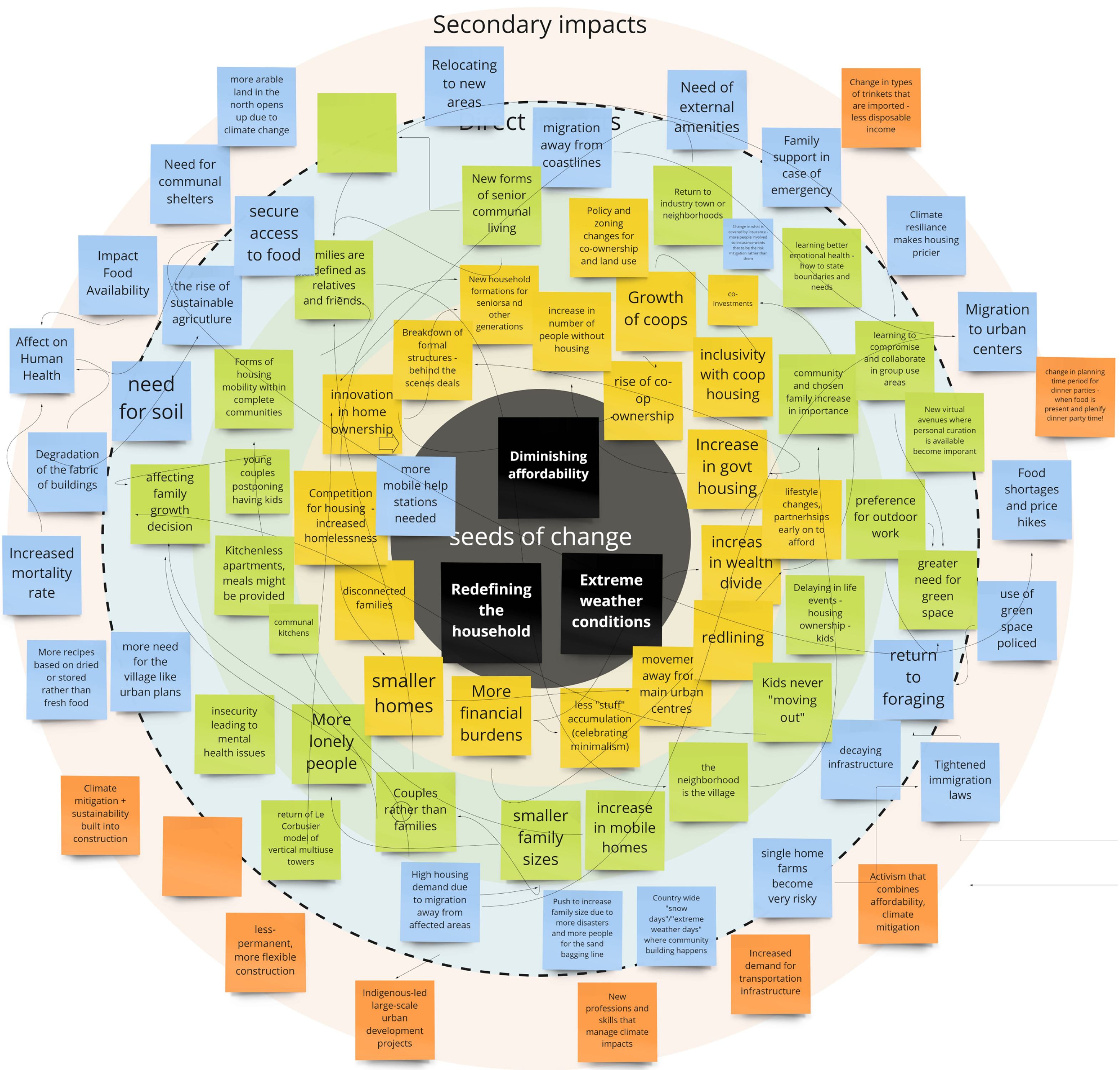


Figure 24

Futures Wheels 2.0, Participants Identify Secondary Impacts of the three Seeds of Change



Seeds of Change (Foresight Signals)

SOCIETY

Growing Density & Diversity

Population growth in the Greater Toronto and Hamilton area is mainly driven by immigration, and this growth continues to have an increasing impact on the density and ethno-cultural diversity of the area.

Evidence:

- The proportion of people in Ontario living in the GTA increased, from 41 per cent in 1986 to 48 per cent in 2019 (Statistics Canada, 2020a).
- Natural increase has been accounting for less of population growth in Ontario, while immigration has been accounting for more over the past few decades (Statistics Canada, 2020b).

Struggling Public Health

Mental health conditions and chronic diseases are impacting an increasingly larger percentage of the population. The adoption of a sedentary lifestyle, poor dietary habits, combined with an aging population, are leading to an increase in chronic diseases. Pandemic fatigue and isolation will potentially result in a mental health crisis following the pandemic.

Evidence:

- Growing number of people facing severe disease at a young age (Szklarski, 2021).
- 74% of Ontarians are experiencing increased mental health and substance use challenges during the pandemic (CMHA, 2021).
- A ten-year observational study found an in crease of 11% in number of patients with chronic disease (Steffler et al., 2021).

Redefining the Household

Alternative housing arrangements are emerging with the growing ethno-cultural diversity in the Greater Toronto and Hamilton Area and housing unaffordability -- think intergenerational households and intentional communal living where members may not belong to the same generation of a family, or the same family, and where household sizes rise above the national average.

Supporting Headlines:

- “Roommates, multi-generational homes rising amid increasing costs” (Deschamps, 2022).
- “Is the boom in communal living really the good life?” (Howard, 2021).
- “Is communal living for you? Sudbury group wants to create 'intentional community'” (Lakes, 2017).

Diminishing Boundaries

The boundaries between home, work, and school were aggressively and abruptly disrupted with the introduction of remote work and learning since the start of the pandemic. Employees are working long hours beyond the 9-5 schedule, and are able to participate in more family activities throughout their day.

Supporting Headlines:

- “Ontario's right to disconnect law too vague to help work-life balance, experts say” (McKenzie-Sutter, 2022).
- “Work-life balance in a pandemic: a public health issue we cannot ignore” (Rudnicka et al., 2021).

Avatar Society

Escalating real-estate values is making the operation of physical businesses increasingly more costly. Extreme pandemics could make physical proximity more risky. Fear of crime and concerns about public safety are on the rise. In-person interactions could become increasingly difficult, costly, risky, and rare, while virtual interaction through the Metaverse becomes a more convenient, cost-effective, and safe alternative.

Supporting Headlines:

- “Why some parents are sticking with remote learning—even as schools reopen” (Saavedra et al., 2021).
- “Why Are Some Kids Thriving During Remote Learning?” (Fleming, 2020).
- “‘Zoom towns’ are exploding in the West” (Smith, 2020).

TECHNOLOGY

Digital Divide

There is a growing gap in access to communications technology between developed and developing countries, urban and rural populations, young and old, and men and women. This is leading to substantial disparities in access to resources, healthcare, goods and services, and education. You could argue that digital access has become one of the main social determinants of health.

Supporting Headlines:

- "Is the Digital Divide the Newest Social Determinant of Health?" (Heath, 2021).
- "Low internet access is driving inequality" (García-Escribano, 2020).

Electrifying Transportation

There is an urgent and fast movement towards zero-emission, electricity-powered transportation to meet climate and sustainability targets. Cities and countries are committing to electrifying their transportation systems including private and public vehicles.

Supporting Headlines:

- "Moving towards a future with battery electric bus transit fleets" (Metrolinx, 2022).
- "The CIB to invest up to $68 million in Durham Region's battery electric buses" (Durham, 2022).
- "City working toward all-electric bus fleet by 2035" (Gillis, 2022).

Robots Robots Everywhere

The proliferation of drone delivery services, robotic mobility aids, flying cars, and electric micro mobility devices will make it necessary for cities to re-consider the design of buildings and public realm and account for the space needed for the operation of these vehicles and devices, both on land and in air.

Supporting Headlines:

- “Drone Delivery Canada begins cargo routes at Edmonton International” (Wings, 2022).
- “People have talked about ‘flying cars’ for decades. Now they may actually happen” (Kharpal, 2022)
- “What?! Dumpling House introduces new robot waiter” (Suh, 2022).

Community-Owned Data

Smart cities use sensors and meters to collect and analyze data, then use this data to improve the city's operations and infrastructure. Since this data is generated through complex and overlapping interactions between citizens and institutions, the question around who owns the data once collected is pertinent to citizen rights in the context of smart cities.

Supporting Headlines:

- “In Brainport Smart District, residents will own their data” (Smart Cities World, 2020).

Micro-Mobility

Bicycles, e-bikes, electric scooters, electric skateboards, shared bicycle fleets, and electric-pedal-assisted bicycles, are all becoming increasingly more popular as primary transportation devices replacing cars. Designated bicycle lanes, protected intersections, dense urban fabric, mixed-use, and transit-oriented development are all factors supporting this trend.

Supporting Headlines:

- “Lime e-scooters integrated with Uber app in London and Milton Keynes” (Smart Cities World, 2022).
- “Ontario e-scooter pilot creates choices as London plans bike-share program” (Stacy, 2020).
- “Growing e-bike popularity in Canada takes the national spotlight on World Bike Day” (Yakub, 2022).

ECOLOGY

Extreme Weather Events

There is a growing gap in access to communications technology between developed and developing countries, urban and rural populations, young and old, and men and women. This is leading to substantial disparities in access to resources, healthcare, goods and services, and education. You could argue that digital access has become one of the main social determinants of health.

Supporting Headlines:

- “Analysis reveals how climate change is influencing extreme weather” (Reuters, 2022).
- “Cities urged to prepare for more extreme urban heat” (Smart Cities World, 2022).
- “Canada is warming twice as fast as the rest of the world” (O'Malley, 2019).

Extreme Pandemics Era

Climate change and extreme weather events are directly linked to the spread of infectious diseases. Floods can lead to outbreaks of water-born diseases, and the destruction of animal habitats can lead to outbreaks of animal-borne diseases. Global travel and urbanization help the rapid spread of outbreaks. The eruption of intense pandemics that impact a large percentage of populations globally and last a significant amount of time is becoming increasingly more likely.

Supporting Headlines:

- “Climate change will force new animal encounters — and boost viral outbreaks” (Gilbert, 2022).
- “How Climate Change Is Contributing to Skyrocketing Rates of Infectious Disease” (Lustgarten, 2020).
- “Why deforestation and extinctions make pandemics more likely” (Lustgarten, 2020).

Re-humanizing the Public Realm

Car-dependency has been draining the vibrancy out of sidewalks and streets for decades. Active transportation was shown to improve physical and mental health, social cohesion, and to reduce greenhouse gas emissions. There is a growing trend towards reshaping and reactivating the public realm through improving sidewalks and transforming automobile-centred streets into active pedestrian thoroughfares.

Supporting Headlines:

- “Montreal to make 10 streets pedestrian-only during summer” (Scott, 2022).
- “Toronto Is Officially Transforming Parts Of Yonge Street Into Car-Free Zones” (Gilson, 2021).International” (Wings, 2022).

Return of the Missing Middle

Exclusionary single-family zoning has been a major factor in encouraging suburban sprawl and car dependency, restricting housing supply and affordability, and undermining inclusion. There is a growing trend towards re-introducing mid-size housing typologies such as duplexes, triplexes, fourplexes, courtyard buildings, multi-story apartment complexes, and live/work complexes.

Supporting Headlines:

- “University of Waterloo researchers to study region’s ‘missing middle’ in housing” (Nielson, 2022).
- “One house, four owners: These unique Toronto listings let you own separate floors in a single home” (Alsharif, 2022).

Rewilding

There is a growing call and commitment to bringing back native plants and species to the city. Native, non-invasive, climate-adapted plants that require little maintenance are becoming widely popular alternatives for landscaping. Those in turn form habitats for other species that are gradually repopulating urban areas.

Supporting Headlines:

- “How rewilding brought the butterflies back to Toronto” (Suzuki, 2020).
- “Push is on to ‘rewild’ Ottawa and promote native plants, greenspace protection” (Coombes, 2022).
- “City of Toronto announces PollinateTO Community Grant recipients” (Toronto, 2022).

ECONOMY

Diminishing Affordability

With the escalation of real-estate values due to increasing costs of services and infrastructure, housing affordability continues to diminish in the Greater Toronto and Hamilton Area, making home ownership out of the question for a growing percentage of the population.

Supporting Headlines:

- "Canada needs 3.5 million more homes than projected to restore affordability, says CMHC" (Shecter, 2022).
- "Ontario increases amount landlords can raise rent by highest level in a decade" (Alberga, 2022).
- "Oakville, Burlington and GTA rentals see largest monthly price jump in three years" (Pereira, 2022).

Hybrid Work

As employees value the freedom and flexibility that hybrid work brings, more employers are likely to adopt hybrid work to attract talent, limit the spread of illness, and save on real-estate expenses. Employees will choose which days to come into the office or will be assigned specific days for on-site work. This trend will continue to spread the workforce over a broad, possibly dynamic, geographical region.

Supporting Headlines:

- "Majority of execs confident culture can survive in hybrid setup" (Wilson. 2022).

Remote Work Inequality

The opportunity to work from home differs substantially along lines of age, gender, class, race, and professions. Essential workers such as healthcare providers, drivers, cleaners, and those who keep the supply of food and medicine flowing, have no opportunity to work remotely. Balancing work responsibilities, childcare, virtual schooling, and housework disproportionately affects working mothers.

Supporting Headlines:

- “Inequality in Opportunity to Work from Home an Underlying Condition Likely Aggravated by the Pandemic” (Bouskill & Harold, 2021).
- “Remote work worsens inequality by mostly helping high-income earners” (Tanguay & Lachapelle, 2020).
- “Remote, hybrid work dividing Canadian employees as many required onsite” (Marowits, 2022).

The Rise of Housing COOP's

Non-profit, mixed-income, multi-unit projects jointly managed by residents is a strong candidate model for the housing affordability crisis in the Greater Toronto and Hamilton Area. Residents of COOPs either pay the full rent, or contribute a percentage of their income topped up by a government subsidy. Once the mortgage is paid off, residents are charged for maintenance only, maintaining the units' affordability.

Supporting Headlines:

- “Canada needs a rebirth of co-op housing” (Ross, 2019).
- “Co-ops allow people of all incomes to live affordably in cities. So why aren't we building more?” (Carman, 2022).
- “Ontario may be headed for a new golden age of housing co-ops” (Peters, 2019).

Localizing Food Supply

Major disruptions to global supply chains during the pandemic has highlighted the importance of investing in local food production. There is a growing movement towards localizing food production and processes in rural Ontario.

Supporting Headlines:

- “New agriculture network to share research, tools with Niagara municipalities” (Majtenyi, 2022).
- “Ontario invests $200,000 in Milton for agri-food innovation” (Cerqueira, 2022).
- “Ontario Investing $25 Million to Increase Food Processing Capacity” (Ontario, 2022).

POLITICS

To Police or Not to Police

In the face of increasing crime rates and police violence incidents, whether police budgets should increase or alternative approaches to public safety should be expanded has become the topic of many heated debates. There is a growing acceptance of assigning a smaller role to the police in addressing public safety and a larger role to non-police factors such as housing affordability and mental health care.

Supporting Headlines:

- "As crimes rise, battles rage on about police funding" (Alfonseca, 2022).
- "Police see major budget increases despite majority support for defunding" (Rutland, 2022).

Democratic Fatigue

Discontent with the current voting system and its lack of proportional representation, low levels of civic literacy, and a growing distrust in governments, seem to be decreasing the public's interest in engagement in democratic processes particularly among youth.

Supporting Headlines:

- "'A clear crisis': Ontario voter turnout prompts renewed calls for electoral reform" (McKenzie-Sutter, 2022).
- "The apathy election? Ontario sees lowest voter turnout in its history, early data suggests" (Powers, 2022).

Big-Tech Brother

The proliferation of big data tools, surveillance, and storage is exponentially increasing the amount of information available about individuals, and the ease of accessing and analyzing it. At the same time, privacy protection laws are being downgraded in the name of public safety. Concerns are growing about collaborations between government surveillance agencies and big-data companies and their threat to individual freedoms.

Supporting Headlines:

- “Data surveillance accelerated by pandemic” (Klassen, 2022).
- “Why some fear that big tech data could become a tool for abortion surveillance” (Ortutay, 2022).
- “Canadians in the dark about how their data is collected and used, report finds” (Bronskill, 2022).

From Consultations to Partnerships

Communities' trust in public consultation processes and the role of these consultations in meeting their needs is diminishing. Grassroots, community-led initiatives to improve neighbourhoods through public-private-community partnerships are emerging to bridge the gap between the needs of communities', developers, and policy-makers.

Supporting Headlines:

- “Community-Led Urban Design: the Solution for Gentrification?” (Charles, 2018).
- “How a community-led design initiative in Toronto is redefining neighborhood revitalization from the bottom-up” (Bhatia, 2020).

Revising Codes

Long-standing codes and policies are becoming outdated as they hinder adaptation of the building industry to the housing supply shortage and climate change. There is a growing movement towards revising these codes to meet housing demands and sustainability goals.

Supporting Headlines:

- “Ending exclusionary zoning would boost the housing supply” (Lyall, 2022).
- “City of Vancouver to permit tall wood buildings up to 12 storeys” (Chan, 2020).

VALUES

Distrust

There is a growing sense of distrust and suspicion towards institutions and governments, as information, misinformation, and disinformation become easily confused. It is becoming increasingly more difficult to discern the validity of information.

Supporting Headlines:

- “Canadians’ trust in the news media hits a new low” (Brin & Charlton, 2022).
- “Survey: Bank of Canada's credibility is taking serious blows” (Vecina, 2022).
- “People increasingly distrust media, avoid news out of fatigue, report finds” (Farooqui, 2022).

Maintenance-Driven Culture

There is a growing appreciation of the value of reusing existing products, and the ecological impact of manufacturing and freight. Second-hand shopping, upcycling, and repairing instead of replacing broken devices are becoming popular alternatives to buying new.

Supporting Headlines:

- “Official Pixel Phone Repair Parts Now Available from iFixit” (Gunther, 2022).
- “The gift of thrift: When second-hand shopping started to be stylish” (CBC, 2022).

Return to Nature

There is a shift in the perceived relationship between humans and nature; from humans as outside actors working to conquer and control nature, to humans as part of the ecosystem participating in the natural ecosystem and equally dependent on the health of the ecosystem for survival.

Supporting Headlines:

- “Why these farmers are welcoming muskrats, birds, and snakes” (McLeod, 2021).
- “OPINION: Time to remind ourselves that there’s #OnlyOneEarth and we must live in harmony with nature” (Tiwary, 2022).

Localism

There is a growing realization of the downsides and fragility of globalism and global supply chains, and a newfound appreciation of locally-produced goods and services, deep understanding of local contexts, and the important role localism plays in supporting regional resilience and sustainability.

Supporting Headlines:

- “Product shortages and soaring prices reveal fragility of U.S. supply chain” (Cerullo, 2022).
- “Ontario Investing $25 Million to Increase Food Processing Capacity” (Ontario, 2022).

Renters for Life

Escalating housing prices combined with the new lifestyle possibilities that hybrid and remote work have opened up, home ownership may no longer be the Canadian Dream for many millennials. Renting has become a more desirable long-term alternative for these individuals.

Supporting Headlines:

- “People say renting is 'throwing money away' but I couldn't disagree more. Why I plan to be a renter for life.” (Lockert, 2019).
- “Renting Is Terrible. Owning Is Worse.” (Phillips, 2021).

Scenario 1: Redefining the Local

The physical built environment has become secondary to the virtual one, and localism no longer means what it used to in the 2010's.

Timeframe: 2040's-2050's

Main drivers:

- Growing density and diversity
- Hybrid work
- Electrifying transportation

Population continues to grow in density and diversity. As square footage per person decreases, creative arrangements and housing typologies emerge. Commerce and retail buildings are adapted to live/work spaces. Peak hour congestion decreases, but neighbourhoods become more active and noisy throughout the day, and work/life boundaries get even more blurred.

Vehicle-caused noise pollution is reduced and air quality is significantly improved. Privately owned green spaces become unaffordable, increasing competition over public green space, and leading to conflict between different uses.

With the decreasing availability of physical space, the metaverse becomes an appealing outlet where a lot of activities occur and people can own and customize their environments a lot more freely than in the physical world.

Different levels of localism emerge based on physical proximity, work sector proximity, and general interests. Cohesion in physical neighbourhoods can only be fostered through sharing of food and maintenance of the physical environment.


a
b
c
d
Lead Conversion Ratio
16 : 1
Unqualified leads turned into customers
Leads 4 260
Opportunities 1 886
Negotiation 1002
Proposal 790
Wins 468
33%
Lead-to-Opportunity
14%
Dwight
Sales Manager
7%
Pam
Sales Manager
11%
Michael
Pam
Creed
Dwight
Jim
e
f
g

Scenario 2: Eco-Communal

Permanent cities as we know them are no longer feasible. The unpredictability of weather events has made a new form of nomadism emerge; living within a community and attending to its needs is key for survival

Timeframe: 2040's-2050's

Main drivers:

- Diminishing affordability
- Redefining the household
- Extreme weather conditions

When a weather event hits a location and renders it uninhabitable, residents move away in their mobile units to another location. Residents whose units are destroyed move into widely available mobile communal shelters.

To facilitate this mobility, housing units become increasingly smaller. New units have no kitchens, meals are prepared in communal kitchens where ingredients are brought from mobile farms or through foraging. Longevity and weight are key considerations for the kinds of foods people make and seek.

A modern, urban form of nomadism emerges; living within a community and attending to the community's needs are key for survival. Communities, made up of mobile housing units, kitchens, and farms, equipped with onsite energy generators, move together where weather events dictate, and individuals depend on the strength of their community to survive and flourish.


a
b
KANTINA
bolero
c
d
e
f
g

Scenario 3: Decentralize, Customize, and Integrate

Context supersedes code, and communities take an active role in shaping the environments, amenities, and services they use.

Timeframe: 20-30 years

Main drivers:

- Struggling public health
- Growing digital divide
- From consultations to partnerships

You can live your entire life without leaving the community where your residence is. Communities are now the main unit and public private partnerships are managed through community hubs to initiate, plan, and execute neighbourhood development projects.

Community hubs also play a central role in empowering members to run community-led research, training, providing free access to digital tools, internet, and 3D printing. Some communities manage to provide their members universal basic income.

The quality of life has increasingly become dependent on the local community and their ability to lead flourishing initiatives. In neighbourhoods where such community leadership is absent, issues such as inequality, houselessness, poor mental and physical health Are widespread.


a
b
c
d
e
INFORMATION

Implications for Future Neighbourhoods

Three divergent scenarios were created through this series of workshops, and more scenarios could be created building on the seeds of change not used in these scenarios. While the scenarios diverged quite significantly from the present, there were common themes that the team has noticed running throughout the three scenarios:

Community

All three scenarios share the theme of reconnecting with the community. In **Redefining the Local**, communal living spaces are widespread, and individuals connect with and belong to different virtual and physical communities. In physically-bound communities, a lot more resources and amenities are shared than they are today, and maintaining these resources becomes the basis for community cohesion. In **Eco-Communal**, living within a community and supporting the health of that community become key for survival. Communities have strong internal ties between their members, however, building strong ties with a geographical location is more challenging. In **Decentralize, Customize, and Integrate**, communities take on more responsibility and authorship in fulfilling their needs. Quality of life is closely tied with the physical context and the health of the local community.

In all three scenarios, making space for communities to self-organize is key for neighbourhood resilience.

Localism

Connection with the local context is highlighted in all three scenarios. In **Redefining the Local**, people connect with different local contexts that are physically or digitally mediated. The physical local context provides the most basic needs of food and shelter, while other needs are fulfilled through digital local contexts. In **Eco-Communal**, localism becomes synonymous with community; localism is where the mobile community goes. In **Decentralize, Customize, and Integrate**, the definition of localism is the closest to the one known today.

Each of the three scenarios has a unique perspective on what constitutes a neighbourhood: a physical space or a digital space, a mobile community, or a traditional neighbourhood. These different kinds of neighbourhoods can all come into play in the future of the Greater Toronto and Hamilton Area.

Environmental conditions

In **Redefining the Local**, environmental conditions play a prominent role as constraints for daily activities and living, the need to negotiate environmental resources becomes highlighted, and the metaverse serves as an escape from these constraints. In **Eco-Communal**, facing environmental constraints becomes inevitable. In **Decentralize, Customize, and Integrate**, communities take on the responsibility of navigating local environmental conditions and stewarding natural environments.

In all three scenarios, communities are key players in how environmental sustainability is approached and how environmental conditions are navigated.

The purpose of building the scenarios was to explore how these scenarios could inform some of the project objectives and metrics to be built into generative design. Table 8 summarizes a synthesis of the three scenarios in the form of design objectives that the neighbourhood must fulfill. These objectives may be built into the generative design model or evaluated outside of the model. Either way, building strategic foresight into a generative design process can inform additional design objectives that the team may not have thought of before.

Table 7

Design Objectives Derived from Scenarios

DESIGN OBJECTIVE	SCENARIO		
	Redefining the Local	Eco-Communal	Decentralize, Customize, and Integrate
Facilities and programs in the neighbourhood incentivize residents to share the responsibility of maintaining the neighbourhood.	✓	✓	✓
The neighbourhood offers facilities for communal food growing and cooking.	✓	✓	✓
Residences in the neighbourhood are designed to accommodate a wide range of household sizes and formats.	✓	✓	
Residences in the neighbourhood can be reconfigured to accommodate communal living spaces.	✓	✓	
The neighbourhood provides co-working spaces for remote work.	✓	✓	✓
The neighbourhood offers facilities for community building - community hub.		✓	✓
Charging stations for electric vehicles are provided for residents and are supplied by clean, renewable energy.	✓	✓	
The neighbourhood is self-sufficient: water, energy, and food can be produced onsite or easily accessed locally.		✓	✓
Residents can access their daily needs within a walking distance from their residences.			✓

Co-Generative:

From Generative to Regenerative

“This liberating and nourishing kind of freedom, does not come from the style of the buildings; it comes from the way people feel ownership of the place, and that in turn comes from the way the place has been generated, and by the way that it is continuously being generated as its life goes forward.”

(Alexander et al., 2005 , p. 6)

The introduction of generative design to architecture and urban planning has immense potential in changing the way we design built environments. The use of computational power to generate design solutions can far exceed human capabilities in speed and volume, leading to the possibility of generating novel solutions that fulfill multiple design objectives. However, I think that on its own, it cannot provide solutions to the complexity of problems we face today. Just as impactful as the technology is the way technology is developed and used.

In this report, I have argued that for new technology to provide effective solutions, it must be embedded into the context it is introduced to, without exceeding its limitations even when conditions allow it temporarily. Embedding technology into the context means that it becomes an integral part of the regeneration of its ecosystem. This integration is needed for technology to support the resilience needed to navigate complexity.

Through a causal layered analysis, I have deconstructed aspects of the current generative design paradigm, which emphasize competition, and have then constructed a new paradigm based on the image of perpetuity, which inspires a worldview that values flourishing, abundance, and appropriate participation. My aim was to find an alignment between generative design and regenerative, health generating design.

One of the ways the alternative paradigm can be put into practice is through a revised generative design workflow that incorporates additional "soft" steps into current workflows. These steps include building requisite variety in the project team, exploring and connecting with the physical site, building desired future scenarios, and identifying the level of complexity of design objectives and determining how generative design can be used to serve each objective accordingly.

I have further elaborated on building desired future scenarios as a key step in a health supporting generative design workflow by conducting a participatory foresight workshop to generate a number of future scenarios for neighbourhoods and communities in the Greater Toronto and Hamilton Area. The foresight process resulted in three divergent scenarios which I then used to extract design objectives for a new neighbourhood project.

Here, I synthesize my learnings from this research project into three main themes:

Community

The health of a place determines the wellbeing of the people living in that place, and their wellbeing determines how well they can maintain it.

This is about the human side of the generative design process. The way the project team is formed and the way the work is carried forward is as crucial as developing the algorithms that generate, rank, and evolve solutions. The people who will live in a particular built environment need to be part of the process of designing - in generative design terms, generating - that environment, and being part of that process continues throughout the life of the environment in the form of maintaining it. The interconnectedness between people and place is vital to the health of the ecosystem, and this interconnectedness can be fostered from the beginning of a generative design process.

Addressing the following questions brings forward the role of community in a generative design process:

- Who will live in, and who is/will be impacted by, the neighbourhood/ area/ city/ region being designed?
- Does our team include members representing these groups?
- Does everyone on our team have access, ability, and knowledge to use the generative design tools used in the project?
- Does our design process foster a sense of ownership of the place and process?
- Does our design process foster a sense of community?

Context

To foster connectedness of people and place, it is hard to substitute direct experience and interaction with the place.

This is about establishing and maintaining a direct connection with the physical site throughout the design process. Learning about the site by physically walking through it and knowing its features from a human perspective establishes that connection from the beginning of the process. Exploring the site with the team and creating the generative design concept while on the physical site ensures that some aspects of the solution, in this case the geometry generator, is developed while immediately present on site. Understanding the natural and social ecosystems of the site ensures that objectives and metrics are determined with awareness and respect to the health of the local conditions.

- Addressing the following questions brings forward the role of context in a generative design process:
- Do all our team members have access to the physical site of the project?
- Has everyone on our team visited the physical site?
- How can our team gather at the physical site to develop the design concept?
- Does our team include members who have knowledge about the natural ecosystem of the site?

Complexity

The connectedness between people and place is not maintained through prediction and control, but through appropriate participation.

This is about understanding the nature of the connection with the physical site, and participating appropriately, which, depending on the context and the objectives of the project, could mean a top-down approach of planning and measuring specific outcomes, or a bottom-up approach of making space for outcomes to emerge. Developing an awareness of the complexity of variables that the project aims to influence, and how far this influence can be determined beforehand helps better-informed participation.

Addressing the following questions supports appropriate participation with complexity in a generative design process:

- Are the factors leading to achieving a specific objective fully understood, or is there room for unexpected results to occur due to factors that were not seen or considered?
- Is computational generative design the best approach to evaluate how well a particular objective is fulfilled, or are there other approaches that are more conducive to achieving these objectives?
- Are we determining design objectives based on what is easily measurable, or are design objectives determined solely by the needs of the people and place?

So, what is a regenerative, generative design approach?

At this point in my learning journey, I think it is **Co-generative**; a context-informed, community-led, complexity-sensitive, computationally-augmented design approach where design collaborators focus on identifying design objectives and designing the steps for generating alternatives, and where computers support in generating, evaluating, and/or improving design alternatives to find synergies to fulfill these objectives.

What is more valuable than this answer, however, is the question itself, and our ability to ask and live the questions that might come out of it.

“By living and loving the questions more deeply we can rediscover the beauty and abundance around us, find deep meaning in belonging to the universe, deep joy in nurturing relationships with all of life, and deep satisfaction in co-creating a thriving and healthier life for all. Questions, more than answers, are the pathway to collective wisdom.”

(Wahl, 2016, p. 19)

Bibliography

General References

Albrecht, K. (2012). The (Only) 5 Fears We All Share | Psychology Today Canada. https://www.psychologytoday.com/ca/blog/brainsnacks/201203/the-only-5-fears-we-all-share

Alexander, C., Schmidt, R., Alexander, M. M., Hanson, B., & Mehaffy, M. (2005). Generative code: The path to building welcoming, beautiful, sustainable neighbourhoods. https://www.livingneighborhoods.org/library/generativecodesv10.pdf

ARUP. (2018). Drivers of Change: Urbanization 2.0. https://www.arup.com/en/perspectives/publications/research/section/drivers-of-change

Autodesk. (2021a). Solvers. Generative Design Primer. https://www.generativedesign.org/02-deeper-dive/02-01_algorithms/02-01-04_solvers

Autodesk. (2021b). What are Algorithms? Generative Design Primer. https://www.generativedesign.org/02-deeper-dive/02-01_algorithms/02-01-01_what-are-algorithms

Autodesk. (2021c). What is Generative Design? Generative Design Primer. https://www.generativedesign.org/01-introduction/01-02_generative-design/01-02-01_what-is-generative-design

Boggess, L. (Director). (2021, April 22). The interconnected web of life: What nature can teach us about cooperation. https://www.youtube.com/watch?v=BaflyMQdY2w

Brampton. (2022). City of Brampton | Brampton 2040 Vision | Brampton 2040 Vision. Brampton. https://www.brampton.ca/EN/City-Hall/Brampton-2040-Vision/Pages/Welcome.aspx

Caetano, I., Santos, L., & Leitão, A. (2020). Computational design in architecture: Defining parametric, generative, and algorithmic design. Frontiers of Architectural Research, 9(2), 287–300. https://doi.org/10.1016/j.foar.2019.12.008

Caldas, L. (2006). GENE_ARCH: An Evolution-Based Generative Design System for Sustainable Architecture. In I. F. C. Smith (Ed.), Intelligent Computing in Engineering and Architecture (pp. 109–118). Springer. https://doi.org/10.1007/11888598_12

Capra, F. (1996). The Web of Life: A New Scientific Understanding of Living Systems. Doubleday.

Chang, S., Saha, N., Castro-Lacouture, D., & Pei-Ju Yang, P. (2019). Generative design and performance modeling for relationships between urban built forms, sky opening, solar radiation and energy. Energy Procedia, 158, 3994–4002. https://doi.org/10.1016/j.egypro.2019.01.841

Charalampidis, E., & Tsalikidis, I. (2015, June 22). A parametric landscape design approach for urban green infrastructure development.

CNU. (2015). The Charter of the New Urbanism. Congress for the New Urbanism. https://www.cnu.org/who-we-are/charter-new-urbanism

CognitiveEdge (Director). (2010, July 11). The Cynefin Framework. https://www.youtube.com/watch?v=N7oz366X0-8

Cowie, R. H., Bouchet, P., & Fontaine, B. (2022). The Sixth Mass Extinction: Fact, fiction or speculation? Biological Reviews, 97(2), 640–663. https://doi.org/10.1111/brv.12816

Curry, A., & Schultz, W. (2009). Roads Less Travelled: Different Methods, Different Futures. 26.

Delgado-Ron, J. A. (2020). Supporting the creation of walkable complete communities: Understanding walkability through a holistic lens. Https://Sustain.Ubc.ca/Teaching-Applied-Learning/Sustainability-Scholars-Program/Project-Library. https://hcommons.org/deposits/item/hc:42545/

Donaldson, K. L. (2019). Compromises and comparisons of complete communities [Thesis]. https://doi.org/10.26153/tsw/5271

Douglas, M. J., Watkins, S. J., Gorman, D. R., & Higgins, M. (2011). Are cars the new tobacco? Journal of Public Health, 33(2), 160–169. https://doi.org/10.1093/pubmed/fdr032

Duany, A., Speck, J., & Lydon, M. (2010). The Smart Growth Manual. McGraw Hill.

Dufva, M., & Rowley, C. (2022). Weak signals 2022: Stories about futures. Sitra. https://www.sitra.fi/en/publications/weak-signals-2022/

Eisenstein, C. (2013). The More Beautiful World Our Hearts Know Is Possible. North Atlantic Books.

Evenson, J., & Cancelli, A. (2018). Visualizing Density and the Drivers of Complete Communities. 133–141.

Finger, M., & Portmann, E. (2016). What Are Cognitive Cities? In Studies in Systems, Decision and Control (pp. 1–11). https://doi.org/10.1007/978-3-319-33798-2_1

Frazer, J. (2002). Creative Design and the Generative Evolutionary Paradigm. In Creative Evolutionary Systems. Morgan Kaufmann Publishers.

Gatti, R. C. (2011). Evolution is a cooperative process: The biodiversity-related niches differentiation theory (BNDT) can explain why. Theoretical Biology Forum, 104, 35–43.

Gatti, R. C. (2016). A conceptual model of new hypothesis on the evolution of biodiversity. Biologia, 71(3), 343–351. https://doi.org/10.1515/biolog-2016-0032

Gerber, D. J., & Lin, S.-H. E. (2014). Designing in complexity: Simulation, integration, and multidisciplinary design optimization for architecture. SIMULATION, 90(8), 936–959. https://doi.org/10.1177/0037549713482027

Giedrowicz, M. (2015). Parametric Design for Ecological Purposes – Case Studies and Algorithm Examples. Journal of Sustainable Architecture and Civil Engineering, 12(3), 75–85. https://doi.org/10.5755/j01.sace.12.3.12989

Grant, J. L., & Scott, D. E. (2012). Complete Communities Versus the Canadian Dream: Representations of Suburban Aspirations. Canadian Journal of Urban Research, 21(1), 132–157.

Greenbelt Foundation. (2020). Growing Close to Home: Creating Complete Rural Communities. Greenbelt Foundation. https://d3n8a8pro7vhmx.cloudfront.net/greenbelt/pages/12315/attachments/original/1593022385/GB_CompleteCommunities_REPORT_E-ver.pdf?1593022385

Holland, J. (1975). Adaptation in Natural and Artificial Systems. MIT Press. http://www.proquest.com/openview/c78067a39019fb29daf134cf5dfbb2d6/1?cbl=30748&parentSessionId=B3ZN3TgNb71Vx3CuPVJmK1AFQbBblamaS4n%2F66%2FXU2U%3D&pq-origsite=gscholar&accountid=12991

Inayatullah, S. (1998). Causal layered analysis: Poststructuralism as method. Futures, 30(8), 815–829. https://doi.org/10.1016/S0016-3287(98)00086-X

Inayatullah, S., & Milojević, I. (Eds.). (2015). CLA 2.0 Transformative Research in Theory and Practice. https://www.metafuture.org/product/cla-2-0-pdf/

Jones, P. (2014). Systemic Design Principles for Complex Social Systems. In Social Systems and Design (pp. 91–128). https://doi.org/10.1007/978-4-431-54478-4_4

Jones, P., & VanPatter, G. (2009). Understanding Design 1, 2, 3, 4: The Rise of Visual SenseMaking. NextDesign Leadership Institute. https://issuu.com/nextd/docs/understandingdesign1_2_3_4

Kurtz, C. F., & Snowden, D. J. (2003). The new dynamics of strategy: Sense-making in a complex and complicated world. IBM Systems Journal, 42(3), 462–483. https://doi.org/10.1147/sj.423.0462

Longboat, D. M. (2002). Indegenous Perspectives on Death and Dying. University of Toronto.

Mang, P., & Reed, B. (2020). Regenerative Development and Design. In Sustainable Built Environments (pp. 115–141). https://doi.org/10.1007/978-1-0716-0684-1_303

Michael Samuelian, Anthony Townsend, Ben Oldenburg, Sharon Ayalon, Lars Kouwenhoven, & Jinglun (Harrison) Yu. (2021). The Future of Urban Tech. https://futureofurbantech.org/

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. Smart Cities, 4(1), Article 1. https://doi.org/10.3390/smartcities4010006

Mostashari, A. (2011). Cognitive Cities and Intelligent Urban Governance. Network Industries Quarterly, 13(3). https://www.academia.edu/801956/Cognitive_Cities_and_Intelligent_Urban_Governance

Nagy, D., Lau, D., Locke, J., Stoddart, J., Villaggi, L., Wang, R., Zhao, D., & Benjamin, D. (2017). Project discover: An application of generative design for architectural space planning. Proceedings of the Symposium on Simulation for Architecture and Urban Design, 1–8.

Nagy, D., & Villaggi, L. (2020, March 1). Generative Design for Architectural Space Planning | Autodesk University. https://www.autodesk.com/autodesk-university/article/Generative-Design-Architectural-Space-Planning-2020

Nagy, D., Villaggi, L., & Benjamin, D. (2018). Generative Urban Design: Integration of financial and energy design goals in a generative design workflow for residential neighborhood layout. Symposium on Simulation for Architecture and Urban Design 2018. https://www.autodesk.com/research/publications/generative-urban-design

Nagy, D., Villaggi, L., Stoddart, J., & Benjamin, D. (2017). The Buzz Metric: A Graph-based Method for Quantifying Productive Congestion in Generative Space Planning for Architecture. Technology|Architecture + Design, 1(2), 186–195. https://doi.org/10.1080/24751448.2017.1354617

Ohland, G., & Brooks, A. (2012). Are We There Yet? Creating Complete Communities for 21st Century America. Reconnecting America. http://reconnectingamerica.org/assets/PDFs/20121001AreWeThereYet-web.pdf

Ontario. (2020). A place to grow: Growth plan for the Greater Goldern Horesshow. Ontario. https://files.ontario.ca/mmah-place-to-grow-office-consolidation-en-2020-08-28.pdf

O'Sullivan, F. (2022, February 18). Driving Through Paris? That's Going to Get a Lot Tougher in 2024. Bloomberg.Com. https://www.bloomberg.com/news/articles/2022-02-18/paris-is-banning-traffic-crossing-the-city-center-from-2024

Peters, A. (2020, May 15). London is transforming its center into a car-free zone to create more distancing when it reopens. Fast Company. https://www.fastcompany.com/90505673/london-is-transforming-its-center-into-a-car-free-zone-to-create-more-distancing-when-it-reopens

Peters, A. (2022, January 13). Berlin is planning a car-free area larger than Manhattan. Fast Company. https://www.fastcompany.com/90711961/berlin-is-planning-a-car-free-area-larger-than-manhattan

Pfaff, D. W. (2015). The Altruistic Brain: How We Get to Be Naturally Good. Oxford University Press.

Preston, S., Mazhar, M. U., & Bull, R. (2020). Citizen Engagement for Co-Creating Low Carbon Smart Cities: Practical Lessons from Nottingham City Council in the UK. Energies, 13(24), Article 24. https://doi.org/10.3390/en13246615

Qeisi, S. A., & Al-Alwan, H. (2021). Generative Urban Design Concepts and Methods: A Research Review. IOP Conference Series: Materials Science and Engineering, 1090(1), 012085. https://doi.org/10.1088/1757-899X/1090/1/012085

Reed, B. (2007). Shifting from 'sustainability' to regeneration. Building Research & Information, 674–680. https://doi.org/10.1080/09613210701475753

Ridolfi, G., & Saberi, A. (2019). Computational Intelligences in the post-Environmental Design. Examples from MAILB. AGATHÓN | International Journal of Architecture, Art and Design, 5, 31–40. https://doi.org/10.19229/2464-9309/542019

Schultz, W. (2015). Manoa: The future is not binary. APF Compass. https://www.researchgate.net/publication/275338406_Manoa_The_future_is_not_binary

Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: A pathways practice for transformation. Ecology and Society, 21(2). https://doi.org/10.5751/ES-08388-210247

Singh, V., & Gu, N. (2012). Towards an integrated generative design framework. Design Studies, 33(2), 185–207. https://doi.org/10.1016/j.destud.2011.06.001

Snowden, D. (2021). Cynefin. Cynefin. https://cynefin.io/wiki/Cynefin

Tapias, E., & Schmitt, G. (2014). Climate-sensitive Urban Growth: Outdoor Thermal Comfort As An Indicator For The Design Of Urban Spaces. WIT Transactions on Ecology and the Environment, 191, 623-. https://doi.org/10.2495/SC140521

The Natural Step. (2008, September 12). Applying the ABCD Method. The Natural Step Canada. https://www.naturalstep.ca/abcd

Toderian, B. (2022, April 12). Finish this sentence: "In the next 5-10 years, cities will…." [Tweet]. Twitter. https://twitter.com/BrentToderian/status/1513760091274551297

Toker, Z., & Pontikis, K. (2011). An inclusive and generative design process for sustainable urbanism: The case of Pacoima. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 4(1), 57–80. https://doi.org/10.1080/17549175.2011.559956

Transit Oriented Development Institute. (n.d.). Transit Oriented Development. TOD. Retrieved December 20, 2022, from http://www.tod.org/

Van Alstyne, G., & Logan, R. K. (2007). Designing for emergence and innovation: Redesigning design. Artifact, 1(2), Article 2.

Villaggi, L., Stoddart, J., Nagy, D., & Benjamin, D. (2017). Survey-Based Simulation of User Satisfaction for Generative Design in Architecture. Design Modeling Symposium 2017. https://www.autodesk.com/research/publications/user-satisfaction-for-generative-design

Wade-Benzoni, K. A., Tost, L. P., Hernandez, M., & Larrick, R. P. (2012). It's Only a Matter of Time: Death, Legacies, and Intergenerational Decisions. Psychological Science, 23(7), 704–709.

Wagner, S., Roorda, M., & Diamond, S. (in review). Planning complete communities using generative design [Unpublished manuscript].

Wahl, D. (2016). Designing Regenerative Cultures. Triarchy Press Ltd.

Wahl, D. C. (2007). Scale-linking design for systemic health: Sustainable communities and cities in context. International Journal of Ecodynamics. Vol, 2(1), 1–16. https://doi.org/10.2495/ECO-V2-N1-57-72

Walmsley, K., & Villaggi, L. (2019, January 4). Generative Urban Design. Autodesk University. https://medium.com/autodesk-university/generative-urban-design-43f4ea48039d

Seeds of Change References (Foresight Signals)

Alberga, H. (2022, June 29). Ontario increases amount landlords can raise rent by highest level in a decade. Toronto. https://toronto.ctvnews.ca/ontario-increases-amount-landlords-can-raise-rent-by-highest-level-in-a-decade-1.5968069

Alfonseca, K. (2022). As crimes rise, battles rage on about police funding. ABC News. https://abcnews.go.com/US/crimes-rise-battles-rage-police-funding/story?id=83392650

Alsharif, G. (2022, June 9). One house, four owners: These unique Toronto listings let you own separate floors in a single home. Thestar.Com. https://www.thestar.com/business/real_estate/2022/06/09/one-house-four-owners-two-unique-toronto-listings-let-you-own-separate-floors-in-a-single-home.html

Bhatia, A. (2020, September 14). How a community-led design initiative in Toronto is redefining neighborhood revitalization from the bottom-up. Brookings. https://www.brookings.edu/blog/the-avenue/2020/09/14/how-a-community-led-design-initiative-in-toronto-is-redefining-neighborhood-revitalization-from-the-bottom-up/

Bouskill, K. E., & Harold, S. W. (2021, May 14). Inequality in Opportunity to Work from Home an Underlying Condition Likely Aggravated by the Pandemic. https://www.rand.org/blog/2021/05/inequality-in-opportunity-to-work-from-home-an-underlying.html

Brin, C., & Charlton, S. (2022). Canadians' trust in the news media hits a new low. The Conversation. http://theconversation.com/canadians-trust-in-the-news-media-hits-a-new-low-184302

Bronskill, J. (2022, May 18). Canadians in the dark about how their data is collected and used, report finds. The Globe and Mail. https://www.theglobeandmail.com/canada/article-canadians-in-the-dark-about-how-their-data-is-collected-and-used/

Carman, T. (2022, March 7). Co-ops allow people of all incomes to live affordably in cities. So why aren't we building more? | CBC News. CBC. https://www.cbc.ca/news/canada/co-op-housing-affordability-1.6374412

CBC. (2022, June 2). The gift of thrift: When second-hand shopping started to be stylish | CBC Archives. CBC. https://www.cbc.ca/archives/second-hand-shopping-archives-1.6470989

Cerqueira, C. (2022). Ontario invests $200,000 in Milton for agri-food innovation. FM101 Milton Now. https://www.miltonnow.ca/2022/04/05/100611/

Cerullo, M. (2022). Product shortages and soaring prices reveal fragility of U.S. supply chain. https://www.cbsnews.com/news/product-shortages-inflation-supply-chain-2022/

Chan. (2020). City of Vancouver to permit tall wood buildings up to 12 storeys | Urbanized. https://dailyhive.com/vancouver/vancouver-tall-wood-buildings

Charles, B. (2018, July 19). Community-Led Urban Design: The Solution for Gentrification? Giving Compass. https://givingcompass.org/article/community-led-urban-design-the-solution-for-gentrification

CMHA. (2021). Everything Is Not OK: 74% of Ontarians experiencing increased mental health and substance use challenges during the pandemic. CMHA Simcoe County. https://cmhastarttalking.ca/news/everything-is-not-ok-74-of-ontarians-experiencing-increased-mental-health-and-substance-use-challenges-during-the-pandemic/

Coombes, C. (2022, April 7). Push is on to “rewild” Ottawa and promote native plants, greenspace protection. Capital Current. https://capitalcurrent.ca/push-is-on-to-rewild-ottawa-and-promote-native-plants-greenspace-protection/

David Suzuki. (2020, June 7). How rewilding brought the butterflies and other pollinators back to Toronto. Streets Of Toronto. https://streetsoftoronto.com/the-rewilding-of-toronto-butterflyway-project/

Deschamps, T. (2022). Roommates, multi-generational homes rising amid increasing costs, immigration: Census. https://www.msn.com/en-ca/news/canada/roommates-multi-generational-homes-rising-amid-increasing-costs-immigration-census/ar-AAZxfQe?rc=1&ocid=winp1taskbar&cvid=54df057d12cd4b9eb0a1bf8cc44cef87

Durham. (2022, June 9). The CIB to invest up to $68 million in Durham Region’s battery electric buses. https://www.durham.ca/en/news/the-cib-to-invest-up-to-68-million-in-durham-region-s-battery-electric-buses.aspx

Farooqui, S. (2022, June 15). People increasingly distrust media, avoid news out of fatigue, report finds. The Globe and Mail. https://www.theglobeandmail.com/canada/article-report-finds-people-increasingly-distrust-media-avoid-news-out-of/

Fleming, N. (2020). Why Are Some Kids Thriving During Remote Learning? Edutopia. https://www.edutopia.org/article/why-are-some-kids-thriving-during-remote-learning/

García-Escribano, M. (2020, July 5). Low internet access is driving inequality | CNN Business. CNN. https://www.cnn.com/2020/07/05/perspectives/internet-access-inequality/index.html

Gilbert, N. (2022). Climate change will force new animal encounters—And boost viral outbreaks. Nature, 605(7908), 20–20. https://doi.org/10.1038/d41586-022-01198-w

Gillis, L. (2022). City working toward all-electric bus fleet by 2035. Sudbury.Com. https://www.sudbury.com/local-news/city-working-toward-all-electric-bus-fleet-by-2035-5435984

Gilson, P. J. (2021, February 4). Toronto Is Officially Transforming Parts Of Yonge Street Into Car-Free Zones (PHOTOS). Narcity. https://www.narcity.com/toronto/yonge-street-is-being-transformed-into-a-pedestrianonly-zone-photos

Gunther, C. (2022). Official Pixel Phone Repair Parts Now Available from iFixit – Review Geek. https://www.reviewgeek.com/122122/official-pixel-phone-repair-parts-now-available-from-ifixit/

Heath, S. (2021, March 10). Is the Digital Divide the Newest Social Determinant of Health? PatientEngagementHIT. https://patientengagementhit.com/news/is-the-digital-divide-the-newest-social-determinant-of-health

Howard, S. (2021, January 17). Is the boom in communal living really the good life? The Observer. https://www.theguardian.com/society/2021/jan/17/is-the-boom-in-communal-living-really-the-good-life

Kharpal, A. (2022). People have talked about “flying cars” for decades. Now they may actually happen. CNBC. https://www.cnbc.com/video/2022/06/13/when-will-flying-cars-hit-our-skies.html

Klassen, V. (2022, June 1). Data surveillance accelerated by pandemic. Queen’s Gazette | Queen’s University. https://www.queensu.ca/gazette/stories/data-surveillance-accelerated-pandemic

Lakes, J. (2017, May 22). Communal living: Get your own home but share neighbourhood and responsibilities | CBC News. CBC. https://www.cbc.ca/news/canada/sudbury/communal-living-sudbury-1.4123390

Lockert, M. (2019). People say renting is “throwing money away” but I couldn’t disagree more. Why I plan to be a renter for life. Business Insider. https://www.businessinsider.com/personal-finance/i-plan-to-rent-for-life-instead-of-buying-home-2019-6

Lustgarten, A. (20 C.E.). How Climate Change Is Contributing to Skyrocketing Rates of Infectious Disease. ProPublica. https://www.propublica.org/article/climate-infectious-diseases

Lyall, R. (2022). Ending exclusionary zoning would boost the housing supply | Canadian Real Estate Wealth. https://www.canadianrealestatemagazine.ca/news/ending-exclusionary-zoning-would-boost-the-housing-supply-335138.aspx

Majtenyi, C. (2022). New agriculture network to share research, tools with Niagara municipalities. The Brock News, a News Source for Brock University. https://brocku.ca/brock-news/2022/06/new-agriculture-network-to-share-research-tools-with-niagara-municipalities/

Marowits, R. (2022). Remote, hybrid work dividing Canadian employees as many required on-site—National | Globalnews.ca. https://globalnews.ca/news/8897956/remote-hybrid-work-divisions-canada/

McKenzie-Sutter, H. (2022a, June 7). “A clear crisis”: Ontario voter turnout prompts renewed calls for electoral reform | CBC News. CBC. https://www.cbc.ca/news/canada/toronto/ont-electoral-reform-1.6480756

McKenzie-Sutter, H. (2022b, June 19). Ontario’s right to disconnect law too vague to help work-life balance, experts say | CBC News. CBC. https://www.cbc.ca/news/canada/toronto/ont-labour-disconnect-1.6494010

McLeod, rsha. (2021). Why these farmers are welcoming muskrats, birds, and snakes | TVO Today. https://www.tvo.org/article/why-these-farmers-are-welcoming-muskrats-birds-and-snakes

Metrolinx. (2022). Moving towards a future with battery electric bus transit fleets. https://www.metrolinx.com/en/news/moving-towards-a-future-with-battery-electric-bus-transit-fleets

Nielsen, K. (2022). University of Waterloo researchers to study region's 'missing middle' in housing | Globalnews.ca. https://globalnews.ca/news/8938904/university-waterloo-research-study-missing-middle-affordable-housing/

O'Malley, I. (2019). Canada is warming twice as fast as the rest of the world. https://www.theweathernetwork.com/ca/news/article/global-warming-driving-canadas-temperatures-up-at-twice-global-rate-climate-change-arctic-anomaly

Ontario. (2022). Ontario Investing $25 Million to Increase Food Processing Capacity. News.Ontario.Ca. https://news.ontario.ca/en/release/1001783/ontario-investing-25-million-to-increase-food-processing-capacity

Ortutay, B. (2022, June 28). Why some fear that big tech data could become a tool for abortion surveillance. PBS NewsHour. https://www.pbs.org/newshour/economy/why-some-fear-that-big-tech-data-could-become-a-tool-for-abortion-surveillance

Pereira, G. (2022, June 27). Oakville, Burlington and GTA rentals see largest monthly price jump in three years | inHalton. Insauga | Local Online News. https://www.insauga.com/oakville-burlington-and-gta-rentals-see-largest-monthly-price-jump-in-three-years/

Peters, D. (2019). Ontario may be headed for a new golden age of housing co-ops | TVO Today. https://www.tvo.org/article/ontario-may-be-headed-for-a-new-golden-age-of-housing-co-ops

Phillips, S. (2021, March 11). Renting Is Terrible. Owning Is Worse. The Atlantic. https://www.theatlantic.com/ideas/archive/2021/03/why-its-better-to-rent-than-to-own/618254/

Powers, L. (2022, June 3). Ontario may have just seen the lowest voter turnout in its history | CBC News. CBC. https://www.cbc.ca/news/canada/toronto/lowest-voter-turnout-ontario-history-elections-1.6476344

Reuters ·, T. (2022, June 28). Analysis reveals how climate change is influencing extreme weather | CBC News. CBC. https://www.cbc.ca/news/climate/climate-change-extreme-weather-study-2022-1.6504245

Ross, T. (2019, July 14). Opinion: Canada needs a rebirth of co-op housing. The Globe and Mail. https://www.theglobeandmail.com/business/commentary/article-canada-needs-a-rebirth-of-co-op-housing/

Rudnicka, A., Cook, D., & Newbold, J. (2021). Work-life balance in a pandemic: A public health issue we cannot ignore. The Conversation. http://theconversation.com/work-life-balance-in-a-pandemic-a-public-health-issue-we-cannot-ignore-155492

Rutland, T. (2022, February 1). Police see major budget increases despite majority support for defunding The Breach. The Breach. https://breachmedia.ca/police-see-major-budget-increases-despite-majority-support-for-defunding/

Saavedra, A., Rapaport, A., & Silver, D. (2021, June 8). Why some parents are sticking with remote learning—Even as schools reopen. Brookings. https://www.brookings.edu/blog/brown-center-chalkboard/2021/06/08/why-some-parents-are-sticking-with-remote-learning-even-as-schools-reopen/

Scott, M. (2022). Montreal to make 10 streets pedestrian-only during summer. Montrealgazette. https://montrealgazette.com/news/local-news/montreal-to-make-10-streets-pedestrian-only-during-summer

Shecter, B. (2022). Canada needs 3.5 million more homes than projected to restore affordability, says CMHC. Financialpost. https://financialpost.com/real-estate/cmhc-affordability-new-homes

Smart Cities World. (2020). VIDEO: In Brainport Smart District, residents will own their data. Smart Cities World. https://www.smartcitiesworld.net/video/video/video-in-brainport-smart-district-residents-will-own-their-data

Smart Cities World. (2022a). Cities urged to prepare for more extreme urban heat. Smart Cities World. https://www.smartcitiesworld.net/climate-action/climate-action/cities-urged-to-prepare-for-more-extreme-urban-heat-7788

Smart Cities World. (2022b). Lime e-scooters integrated with Uber app in London and Milton Keynes. Smart Cities World. https://www.smartcitiesworld.net/micromobility/micromobility/lime-e-scooters-integrated-with-uber-app-in-london-and-milton-keynes-7617

Smith, L. (2020, October 17). ‘Zoom towns’ are exploding in the West. Fast Company. https://www.fastcompany.com/90564796/zoom-towns-are-exploding-in-the-west

Stacey, M. (2020). Ontario e-scooter pilot creates choices as London plans bike-share program. Lfpress. https://lfpress.com/news/local-news/ontario-e-scooter-pilot-creates-choices-as-london-plans-bike-share-program

Statistics Canada. (2020a). Ontario’s Long-Term Report on the Economy: Chapter 1: Demographic Trends and Projections | Ontario.ca. https://www.ontario.ca/document/ontarios-long-term-report-economy/chapter-1-demographic-trends-and-projections#section-2

Statistics Canada. (2020b, May 29). Chapter 1: Demographic Trends and Projections. Ontario.Ca. https://www.ontario.ca/document/ontarios-long-term-report-economy/chapter-1-demographic-trends-and-projections

Steffler, M., Li, Y., Weir, S., Shaikh, S., Murtada, F., Wright, J. G., & Kantarevic, J. (2021). Trends in prevalence of chronic disease and multimorbidity in Ontario, Canada. CMAJ: Canadian Medical Association Journal = Journal de l’Association Medicale Canadienne, 193(8), E270–E277. https://doi.org/10.1503/cmaj.201473

Suh, E. (2022). What?! Dumpling House introduces new robot waiter. Sudbury.Com. https://www.sudbury.com/local-news/what-dumpling-house-introduces-new-robot-waiter-5335110

Szklarski, C. (2021). Decade's worth of Ontario health data finds more severe disease, younger patients | CTV News. https://www.ctvnews.ca/health/decade-s-worth-of-ontario-health-data-finds-more-severe-disease-younger-patients-1.5318563?cache=pawumraq%3FcontactForm%3Dtrue%3FclipId%3D89563

Tanguay, G. A., & Lachapelle, U. (2020). Remote work worsens inequality by mostly helping high-income earners. The Conversation. http://theconversation.com/remote-work-worsens-inequality-by-mostly-helping-high-income-earners-136160

Tiwary, B. (2022). OPINION: Time to remind ourselves that there's #OnlyOneEarth and we must live in harmony with nature. Business Insider. https://www.businessinsider.in/sustainability/article/opinion-time-to-remind-ourselves-that-theres-onlyoneearth-and-we-must-live-in-harmony-with-nature/articleshow/92005247.cms

Tollefson, J. (2020). Why deforestation and extinctions make pandemics more likely. Nature, 584(7820), 175–176. https://doi.org/10.1038/d41586-020-02341-1

Toronto, C. of. (2022, April 19). City of Toronto announces PollinateTO Community Grant recipients (Toronto, Ontario, Canada). City of Toronto; City of Toronto. https://www.toronto.ca/news/city-of-toronto-announces-pollinateto-community-grant-recipients/

Vecina, E. (2022). Survey: Bank of Canada's credibility is taking serious blows. https://www.mpamag.com/ca/news/general/survey-bank-of-canadas-credibility-is-taking-serious-blows/411331

Wilson, J. (2022). Majority of execs confident culture can survive in hybrid setup. https://www.hrreporter.com/focus-areas/culture-and-engagement/majority-of-execs-confident-culture-can-survive-in-hybrid-setup/367815

Wings. (2022, June 6). Drone Delivery Canada begins cargo routes at Edmonton International. Wings Magazine. https://www.wingsmagazine.com/drone-delivery-canada-begins-cargo-routes-at-edmonton-international/

Yakub, M. (2022, June 3). Growing e-bike popularity in Canada takes the spotlight on World Bike Day. Electric Autonomy Canada. https://electricautonomy.ca/2022/06/03/e-bike-canada-world-bike-day/

Appendix A References

Autodesk Research (Director). (2021, November 8). VASA for Dynamo: Comprehensive Guide - Part 1. https://www.youtube.com/watch?v=wE4gk0FYWDw

Autodesk Research. (2022). Project Discover. https://www.autodesk.com/research/projects/project-discover

Bonnafous, E., & Bonnet, J.-H. (2017). Project Fractal, FormIt, and Dynamo Studio: The Perfect Trio During Early Design Phase | Autodesk University. https://www.autodesk.com/autodesk-university/class/Project-Fractal-FormIt-and-Dynamo-Studio-Perfect-Trio-During-Early-Design-Phase-2017

Carlson, W. E. (2017). History of COmputer Graphics and Animation. The Ohio State University. https://ohiostate.pressbooks.pub/graphicshistory/front-matter/cover/

Davis, D. (2013). A History of Parametric. Daniel Davis. https://www.danieldavis.com/a-history-of-parametric/

Eastman, C., & Henrion, M. (1977). GLIDE: A Language for Design Information Systems. ACM SIGGRAPH Computer Graphics, 11(2), 10.

Goldstein, R., Breslav, S., Walmsley, K., & Khan, A. (2020). SpaceAnalysis: A Tool for Pathfinding, Visibility, and Acoustics Analyses in Generative Design Workflows. 8.

Graphisoft. (2022). Our Story. Graphisoft. https://graphisoft.com/why-graphisoft/our-story

McLuhan, M. (1988). Laws of Media: The New Science. University of Toronto Press.

Ogueta, C. M. S. (2012). User Innovation in Digital Design and Construction: Dialectical Relations between Standard BIM Tools and Specific User Requirements [MASSACHUSETTS INSTITUTE OF TECHNOLOGY]. https://insidethefactory.typepad.com/my_weblog/tips-tricks/

Smith, L. (2018, November 12). Introducing Project Refinery. Dynamo BIM. https://dynamobim.org/introducing-project-refinery/

Vermeulen, D. (2019). From Design Automation to Generative Design in AEC | Autodesk University. https://www.autodesk.com/autodesk-university/class/Design-Automation-Generative-Design-AEC-2019-0

Yares, E. (2013, February 13). 50 Years of CAD. Design World. https://www.designworldonline.com/50-years-of-cad/

Photo Credits

p.103a: Photo by Deberarr on Adobe Stock

p.103b: Photo by AYAimages on Adobe Stock

p.103c: Photo by Monkey Business on Adobe Stock

p.103d: Photo by Colin on Adobe Stock

p.103e: Photo by Supamotion on Adobe Stock

p.103f: Photo by Nada Sertic on Adobe Stock

p.103g: Photo by Karelnoppe on Adobe Stock

p.105a: Photo by Satoshi Kina on Adobe Stock

p.105b: Photo by Karsten Winegeart on Unsplash

p.105c: Photo by Alexandros Giannakakis on Unsplash

p.105d: Photo by Chloe Frost-Smith on Unsplash

p.105e: Photo by Kristaps Ungurs on Unsplash

p.105f: Photo by Ivan Kmit on Adobe Stock

p.105g: Photo by Martin Schlecht on Adobe Stock

p.107a: Photo by OCG Saving The Ocean on Unsplash

p.107b: Photo by Zoran Zeremski on Adobe Stock

p.107c: Photo by Monkey Business on Adobe Stock

p.107d: Photo by Ismael Paramo on Unsplash

p.107e: Photo by Rawpixel.com on Adobe Stock

Cover artwork derived from image by Guoquan on Adobe Stock

Appendix A: Evolution of Computer-Aided Design

Phase I: Computer-Aided Documentation

Time period: 1960’s - 1980’s

This phase is marked by the introduction and commercialization of CAD systems that enable designers to digitally draw 2D and 3D forms using command lines and keyboard and mouse input.

Systems introduced

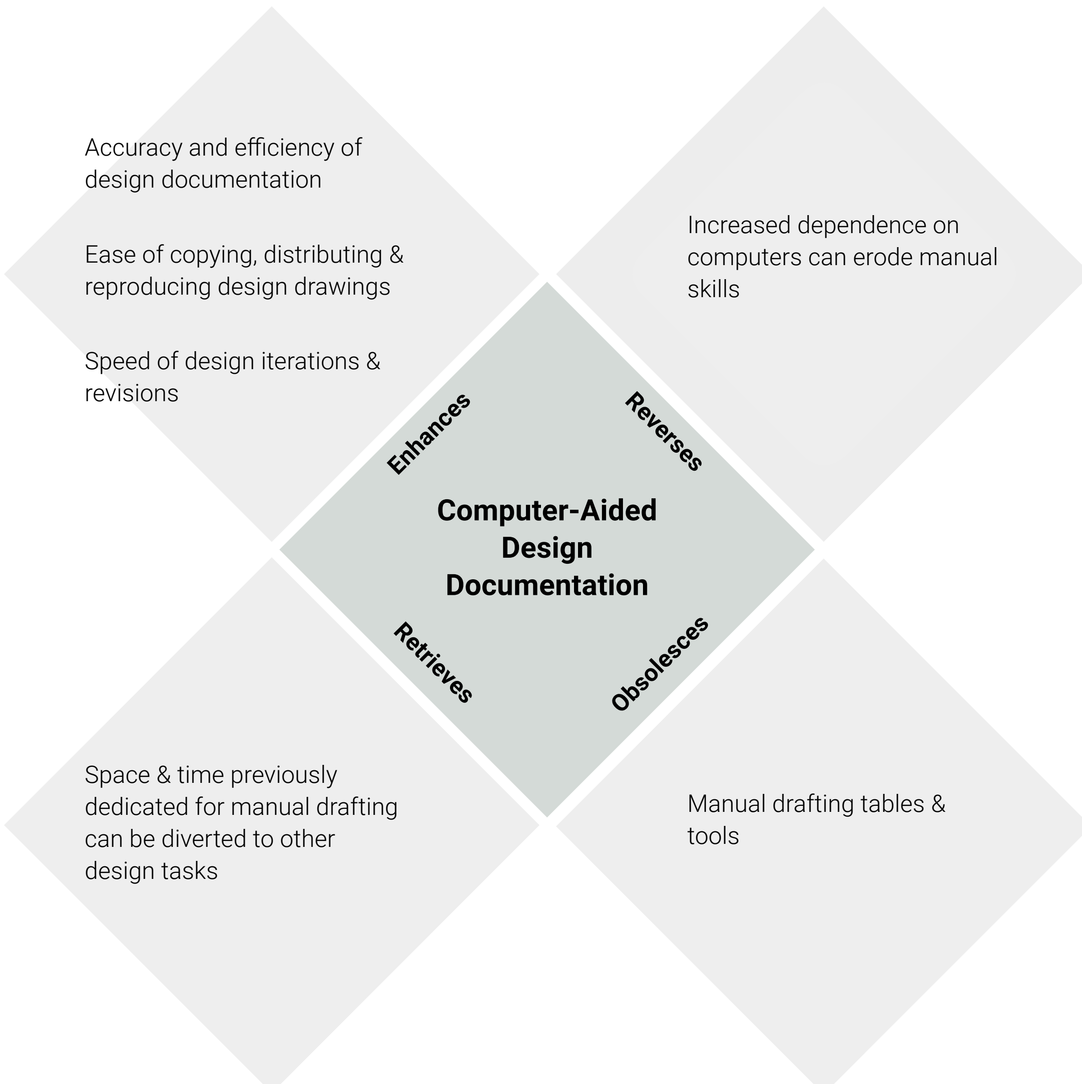
Sketchpad, developed by Ivan Sutherland, allowed the designer to draw 2D shapes directly on the screen using a light pen (Yares, 2013; Davis, 2013). Unisurf, developed by Renault Group and The International Computer Company, utilized linear equations to enable the drawing of 3D surfaces (Davis, 2013). ADAM (Automated Drafting And Machining), developed by Patrick Hanratty, was the first commercially-available design, drafting, and manufacturing system and became the basis for the majority of CAD systems used today (Carlson, 2017). In the early 1980’s, John Walker, along with 15 other co-founders, founded Autodesk and developed AutoCAD 1.0 which became the CAD industry standard (Carlson, 2017). AutoCAD allowed designers to use line commands to draft 2D lines on the computer using a keyboard rather than a pen (Davis, 2013).

Design approach

This phase corresponds with what Vermeulen (2019) calls the traditional design mindset, where the designer uses computers for drafting and recording a single-view representation, such as a plan, an elevation, or a section view, of the design conceptualized in their mind. In that phase, CAD was a faster, more efficient equivalent of traditional pen and paper. The use of CAD software for design documentation remained prevalent until around the late 90’s when Building Information Modeling (BIM) became widespread.

Figure 24

Phase I: Computer-Aided Documentation Tetrad of Effects



Phase II: Parametrization

Time period: 1980's - 1990's

This phase is marked by the introduction of programming languages that can be used to describe geometry and components through parametric equations, and the introduction and commercialization of CAD systems based on these languages. This enables the creation of complex and coherent 3D models that are easy to revise.

Systems introduced

In the 1970's, Charles Eastman and Max Henrion developed GLIDE (Graphical Language for Interactive DEsign) in an attempt to organize operations needed for the design of a physical system into a computer environment (Eastman & Henrion, 1977). Later in the 1980's, Graphisoft introduced ArchiCAD around a parametric programming language that describes 3D solid objects, like doors and windows, and the 2D symbols representing them on the floor plan (Graphisoft, 2022). Parametric Technology Corporation released Pro/ENGINEER, another software that allowed users to effectively associate parts of the geometry using parametric equations (Davis, 2013). Revit was later introduced as a parametric building modeler specifically designed for architects and building professionals to help make changes to a model without having to revise all views manually as the software would "Revise It" instantly (Davis, 2013).

Design approach

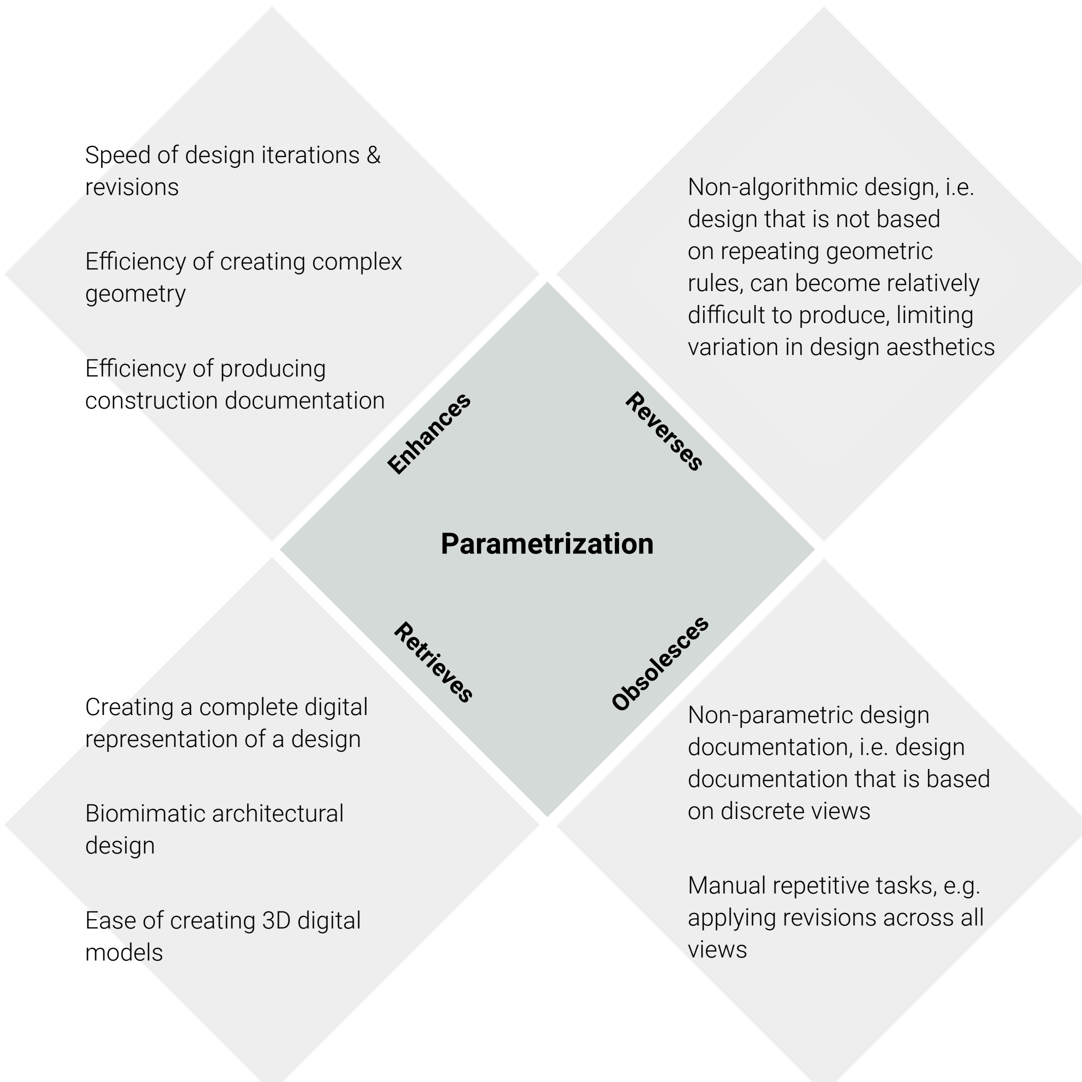
This phase of the evolution of CAD software corresponds with what Vermeulen (2019) calls the parametric design mindset, where designers use computers to:

- create relationships between the elements drawn, referred to as parametric modeling;
- describe a process for creating a specific design outcome, referred to as computational modeling; or
- automate specific tasks by driving parameters with automated scripts, referred to as design automation.

In this approach, the designer defines the form, even though less directly than in the traditional design mindset, and computers have more of a role in generating these forms. These developments transformed CAD from a mere digital equivalent of pen and paper to a robust tool for producing design variations and rapidly making revisions across a design model. With scripting expertise, designers could also customize CAD features to perform repetitive tasks quickly, further speeding up the creation of design variations and applying revisions. In addition, complex forms and assemblies became easier to produce and manage thanks to the diverse 3D CAD software introduced in that phase.

Figure 25

Phase II: Parametrization Tetrad of Effects



Phase III: Visual Programming

Time period: 1990’s - present

This phase is marked by the introduction of visual scripting languages and interfaces into architectural CAD software.

Systems introduced

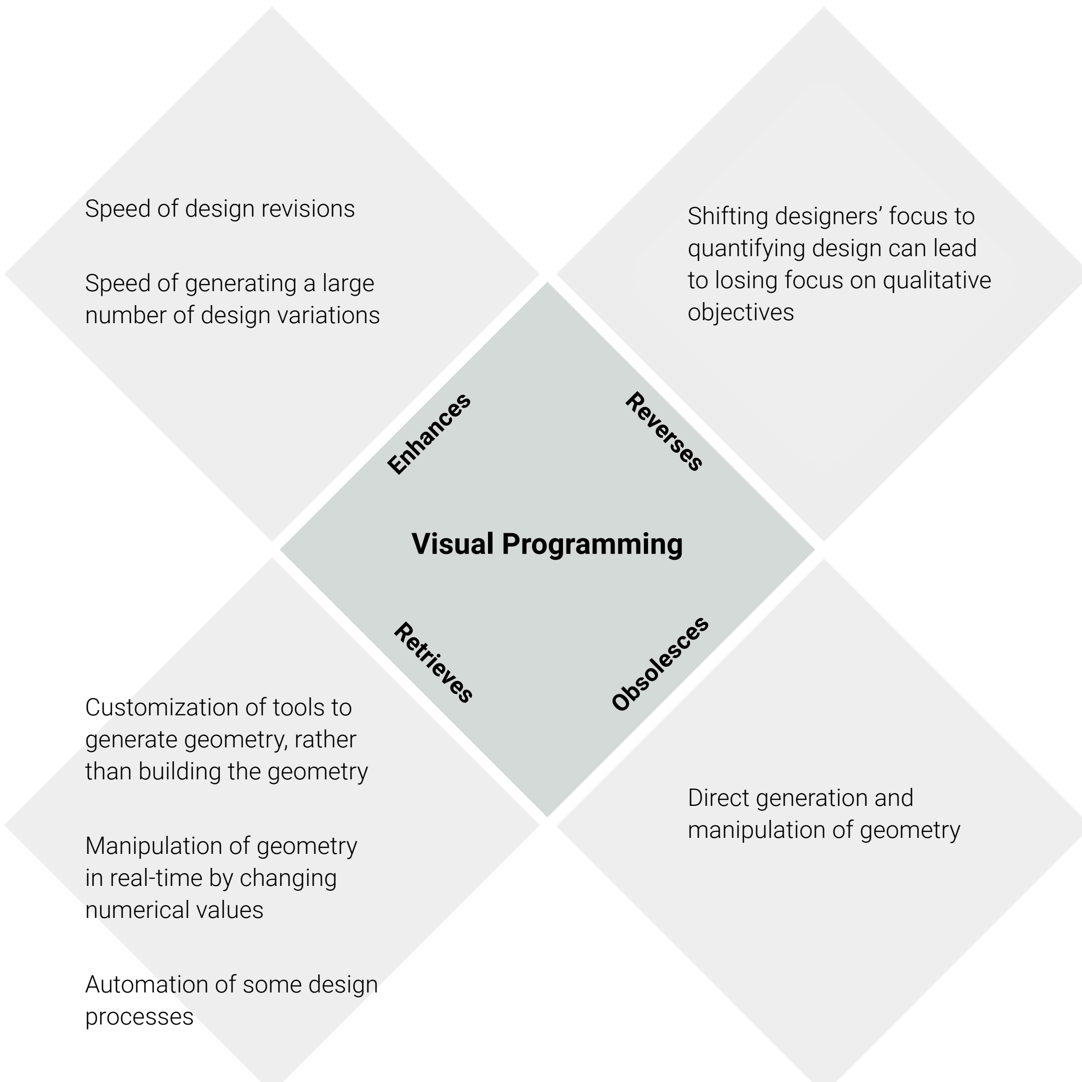
Generative Components was the first introduction of visual scripting specifically developed for architects (Davis, 2013). After a few years of testing with a small number of architecture firms, visual scripting interfaces for architects were commercialized by the release of Generative Components and Grasshopper. Parametric functionality was later added to AutoCAD (Davis, 2013; Engineering, 2016). Dynamo add-in was then developed for Revit which introduced visual programming to the most commonly used BIM software in the architecture industry (Ogueta, 2012).

Design approach

The approach shift in this phase of the evolution of CAD software is a shift in focus from directly designing the form to developing the logic that generates the form. In this approach, the designer is farther removed from the form, and so the focus on subjective qualities of designed spaces and objects, such as aesthetics and beauty, starts to take a backseat in the design process, while function and process start moving to the front.

Figure 26

Phase III: Visual Programming Tetrad of Effects



Phase IV: Generative Design

Time period: 2010’s - present

This phase is marked by the introduction of systems that bring together parametric design tools and optimization algorithms to enable performance-based generation and optimization of design solutions.

Systems introduced

Project Fractal was a web-based project developed by Autodesk with the objective of calculating every possibility for a given problem by computationally changing these parameters (Bonnafous & Bonnet, 2017). Project Fractal then evolved into Project Refinery (Smith, 2018), which added features for setting design objectives and optimizing the solution space for these objectives (Smith, 2018). Project Discover was then launched as a workflow for using generative design in AEC. It integrates algorithmic geometry generation and measuring of goals, with a system for automatically generating, evaluating, and evolving a large number of design options (Autodesk Research, 2022). The workflow has been applied in multiple projects, and new tools were introduced to evolve the workflow such as pathfinding, visibility, and acoustic analysis (Goldstien et al, 2020). The Space Analysis Toolkit includes these analysis tools for 2D models. VASA toolkit was developed to perform similar analysis for 3D models (Autodesk Research, 2021.).

Design approach

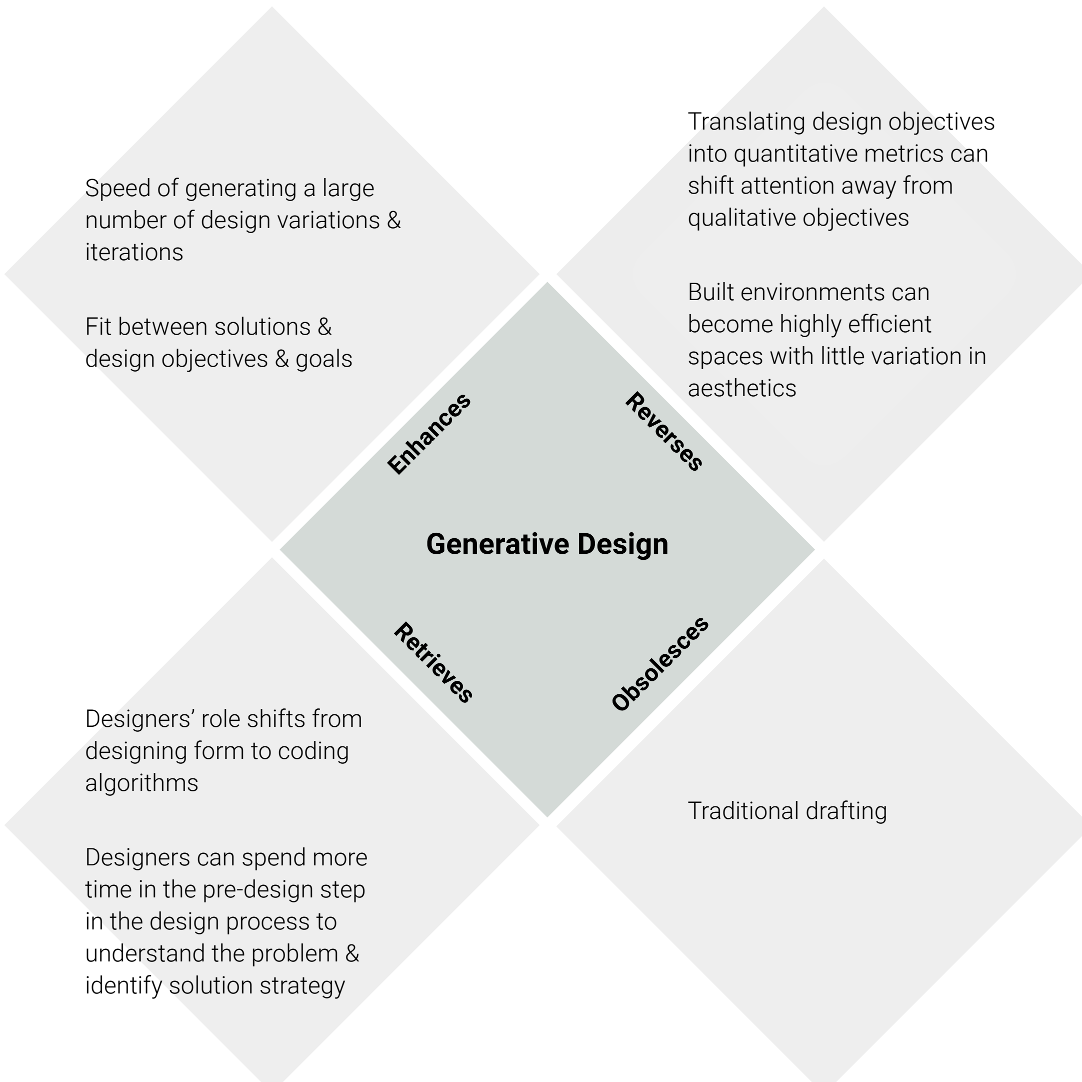
This newest phase of the evolution of CAD software corresponds to what Vermeulen (2019) calls a generative design mindset, where the designer uses computers to:

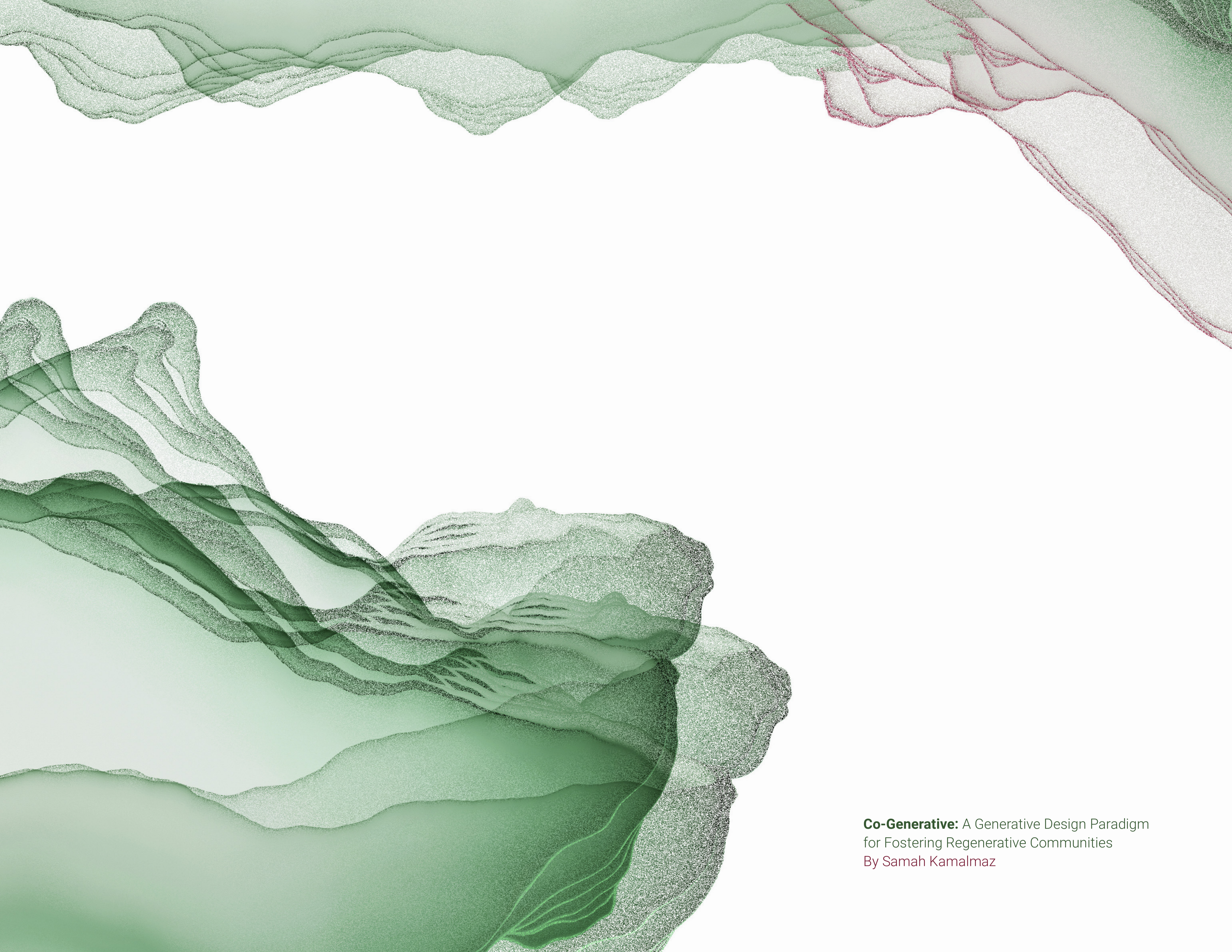
- explore parametrically-generated design variations, referred to as option generation; and
- evaluate these variations based on designer-defined goals, referred to as design optimization.

The evolution of CAD to support generative design workflows in architecture is still in its early stages. In the current workflows, an important role of human designers is to define the goals and objectives of the project and to define quantitative metrics to measure the performance of solutions against these objectives.

Figure 27

Phase IV: Generative Design Tetrad of Effects





Co-Generative: A Generative Design Paradigm
for Fostering Regenerative Communities
By Samah Kamalmaz