



## Full length article

## Expanding perceptions of the circular economy through design: Eight capitals as innovation lenses

André Nogueira<sup>a,\*</sup>, Weslyne S. Ashton<sup>b</sup>, Carlos Teixeira<sup>a</sup><sup>a</sup> Illinois Institute of Technology, Institute of Design, 3137 S Federal St, Chicago, IL, 60616, United States<sup>b</sup> Illinois Institute of Technology, Stuart School of Business, 565 W Adams St, Chicago, IL, 60661, United States

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## ABSTRACT

We widely recognize that systems approaches are necessary to tackle the complex and urgent challenges of the unsustainability of human actions on the planet. However, *how* we perceive systems is largely framed by *who* is included in the discussion and the experiences and interests that they bring to bear. Efforts to create the circular economy aim at closing material loops, but these efforts are limited because they only consider the flows of a few types of capital - natural, manufactured and financial, and are based on specific interests of a few actors. Other types of capital - human, social, political, cultural and digital - are often ignored, and as such the full scope of dynamics in a system is missed. Even though there will always be a discrepancy between what is perceived, and the actual system in operation, there are greater opportunities to expand such perception by drawing more deeply on systems thinking and the concept of capitals. This involves expanding not only the notion of the system itself, but also acknowledging different actors and their interests, types of capital in the system, and interactions between the actors and capital stocks and flows. We develop a systems thinking framework using eight capitals, and apply it in multi-level contexts in the Chicago region to demonstrate how they provide new insights and critical pathways for the transition to the circular economy.

## 1. Introduction

With the advance of modern capitalism, humans have adopted the worldview that resources all around us are to be utilized for our individual and collective benefit. We extract natural resources from the far corners of the planet, push them through global supply chains to meet the needs and aspirations of consumers, while depositing large amounts of waste to the environment at every stage of the process.

Our limited capacity to understand the dynamics of the systems from which these resources were drawn has led to the creation of linear, fragmented models, in which resources flow in one direction creating significant and often irreversible negative ecological impacts. Anthropogenic mobilization of resources is now the dominant driver of impact in many biogeochemical systems, in some cases disrupting the planetary boundaries, or safe spaces, within which these systems function (Rockström et al., 2009). Additionally, how resources are mobilized has often been determined by relatively few parties with specific interests and agenda, raising concerns about power dynamics and injustice in the allocation of benefits and burdens from these resource flows (Gregson et al., 2015). As such, societies have developed sophisticated but degenerative economic models that are now scaling

unsustainable consequences for both social and ecological systems.

There is an inherent tension between the goal to improve the material well-being of a growing human population and the socio-ecological degradation that has resulted from the linear production and consumption of resources created to achieve that goal. The circular economy (CE) presents a reframing of the linear economic system that is based on the belief that resource flows should be cyclical, modeled after many biogeochemical cycles, such as water, carbon and nitrogen. During the last decade, CE has gained tremendous traction among both private companies and public institutions across the world, who are embracing this alternative economic model in order to circumvent this tension (Geng and Doberstein, 2008; Ghisellini et al., 2016; Reike et al., 2018). CE builds on previous academic fields of study and practice areas including industrial ecology, ecological economics, sufficiency economy, The Natural Step and Cradle to Cradle, among others (Bocken et al., 2016; EMF, 2017).

While several methods and frameworks have been explored to support transitions towards more circular economies (Su et al., 2013), organizations still lack sufficient analytical and implementation tools for understanding how systemic approaches should be incorporated into their everyday practices (Bocken et al., 2016), and how they can

\* Corresponding author.

E-mail address: [anogueira@id.iit.edu](mailto:anogueira@id.iit.edu) (A. Nogueira).

inform new collaborations and partnerships within broader systems' contexts (Murray et al., 2017). Murray et al (2017) pointed several unintended consequences of this approach emerging from the application of the concept, such as overly simplistic goals leading to greater environmental impact, or the adoption of circular practices without considering the ethical implications of inclusion, equity and other critical aspects relating the social dimensions of contemporary economic models. Although incremental isolated changes are focused on expanding the circularity and life cycle of products through new services, there remains greater opportunities to prompt paradigm shifts and transitions towards circular economies.

As noted by Antikainen and Valkokari (2016) transitions towards a CE requires innovation across different areas of multiple systems, not only within specific organizations or products. They argue that “system-wide innovations can only be realized in conjunction with related complementary innovations” (p. 6). According to Gaziulusoy and Brezet (2015), “transitions and system innovations are conceptualised as “multi-phase, multi-level dynamic processes,” which take place over long periods of time and result in mainstream practices becoming outdated and being replaced by a set of new practices” (p.1).

Although some conceptualizations of the CE suggest that different types of capital should be regenerated (EMF, 2017), these capitals have not been effectively considered as current work focuses on natural, financial and manufactured capital, and closing material loops based on the interests of organizations that were designed to thrive in linear economic models. While these organizations might intend to engage in CE practices (Babbitt et al., 2018; Kalmykova et al., 2018), their processes do not recognize other types of resources that either sustain these flows, or are compromised by them.

This paper aims to address this gap and expand the CE discussion by leveraging systems thinking to recognize and incorporate consideration of multiple capitals sustaining contemporary economic activities. In particular, we utilize an expanded conception of capital in order to analyze the varied resources that operate within any socio-ecological system. We integrate considerations of the concept of CE, systems thinking approaches, design methods and community capitals framework into the design of the ‘innovation lenses’. This framework has been used to analyze and intervene in complex socio-ecological issues, considering their multi-level interconnectivity and multi-systems interactions, in order to increase the circularity of resource use and benefits to participants.

## 2. Framing the circular economy and multiple capitals

### 2.1. Circular economy

With a global population exceeding 7.5 billion and increasing consumer demand for material goods to improve well-being, the mobilization of natural resources and ensuing socio-ecological interactions have been transformed. Haas et al (2015) assessed the utilization of material and energy in the global economy at the turn of the twenty-first century. The authors concluded that “global in-use material stocks are growing at a high rate” (p.772), and that new ways of designing products are necessary. Indeed, products physically result from the combination of material and energy, but also from knowledge, ideas, and technology. Redesigning production systems to meet the demands of a growing global population presents complex and ambiguous challenges that require not only more sustainable management of material and energy, but also the recognition of different types of resources and values shaping current economic transactions.

The concept of circular economy can inform the design of new frames, opportunities for innovation and entrepreneurship (Bocken et al., 2016), and the necessary paradigm shift in the business ecosystem (Lacy and Rutqvist, 2016). The CE aims to transform existing dynamics of linear and fragmented production-consumption systems into an economic model where resources are cycled through closed

loops, greater value is realized during end-of-life product stages, and different types of capital are regenerated, benefiting society and the planet (Kirchherr et al., 2017). It further suggests that current operations can be optimized through effective networking, partnership activation, and intensive collaboration.

CE has been explored mostly through the lenses of material flows and extensions of product life cycles aiming to close loops through new collaborations. The processes and compositions of partnerships, the importance of relationships, the creation of networks and formation of new alliances have been little explored and present complex challenges that go beyond current circular economy practices. If organizations want to realize a CE, they will have to go beyond the focus of materials flows. They will have to recognize that multiple types of capital are needed to sustain a CE, and as such will have to expand their practices considering the stocks and flows of these capitals, as well as the interactions between their organizational practices and socio-ecological systems in which action is taken. By doing so, organizations can benefit from new opportunities for value creation.

### 2.2. Systems thinking

Systems thinking is a discipline that brings a singular vocabulary and a set of methods for making sense of the complexity observed in social and ecological systems all around us. A significant amount of scientific development during the nineteenth and twentieth century was based on reductionist principles - breaking problems into smaller, more understandable parts. However, the process of understanding the interconnectivity between the parts in order to make sense of the whole was much more complicated than anticipated (Barabási, 2003). Efforts to bridge this knowledge gap carved the path towards systems theory and systems thinking.

Systems thinking methods have allowed researchers to map the structure of relationships among components of a complex system, explore the dynamics of relationships among them, including causal relations and feedback loops, and explore how changes in components or their relationships with other parts affect the whole (Meadows, 2008). While some changes can be predicted, others can lead to unexpected and non-intuitive results. The former leads to understanding patterns of behavior, and the latter to the study of network effects and unintended consequences. The combination leads to the exploration of alternative methods to improve human's perceptions about the systems in which they are embedded, and inform the design of more resilient, robust, and more fit interventions. In order to understand the dynamic behavior of a system, it is necessary to identify subsystems, roughly divided into three levels of complexity: the micro (individual parts), meso (organizations), and macro (social systems), and their interactions (Geels, 2002).

Many disciplines have developed theory and methods to contribute towards behavior change regarding the multi-level interactions between humans and the natural environment (Cote and Nightingale, 2012). Notable to this discussion are two subfields - socio-technical systems and socio-ecological systems - that aim to develop and disseminate knowledge in complex systems theory. Whereas socio-technical systems focus on interaction between human and technical elements in the built environment (Edwards, 2003), socio-ecological systems focus on the social, institutional, and cultural context of the interactions between humans and the natural environment (Capra, 1996; Ostrom, 2009).

Efforts towards circular economy have been primarily informed by knowledge developed in subfields of socio-ecological systems, specifically those related to the circulation of resources considering nutrients, materials, and energy systems, such as industrial ecology. Yet this transition requires interventions in consumer behavior, market rules and dynamics, cultural heritages and social contracts, as well as both the physical and the digital infrastructures through which individuals and organizations produce and consume things. Several subfields of

socio-technical systems have been exploring how to incorporate systems thinking into interventions for transitions, including design.

### 2.3. Design

Design can be understood as a methodological and rigorous choice-making process aimed at intervening in the present to steer actions towards more desirable futures (Simon, 1996). The field of design has been instrumental in advancing innovative practices for systems interventions around the world by centering activity around an understanding of human challenges and motivations, and working as knowledge agents to alter resource flows among different agents (Bertola and Teixeira, 2003). Significant contributions have been made to understand the multi-level nature of systems transitions (Joore and Brezet, 2015), and to incorporate theory from other fields into new tools and methods for systems intervention (Van Ael et al., 2018). The integration of socio-technical concerns into interventions for socio-ecological systems require new approaches to deal with adaptability, decentralized decision-making, integration of dynamic interactions happening within and among these systems, and different agendas of multiple agents (Gaziulusoy and Brezet, 2015). Designers utilize participatory approaches through the concept of “infrastructuring”, suggesting a shift of design outcomes from “what” (artefacts) to “when” (process), bringing the importance of iterative design and the continuous adaptation of systemic interventions (Björgvinsson et al., 2010; Karasti, 2014). This approach can help to explore alternative pathways for transitioning towards more circular economies as it stands for more democratic methods of innovation, and recognizes the adaptive nature of complex systems.

While design has been utilized as a strategic tool for expanding options and supporting the acceleration of innovation processes by focusing on investigating material and symbolic interventions that can shape future livelihoods (Teixeira, 2017), little attention has been given to how products are shaped by and intervene in the dynamic relationship of coupled human-environment systems (Haas et al., 2015). As Whitney (2015) pointed out, the growing social and economic impact on ecological systems is leading to “problems never before seen in human history, involving the carrying capacity of the planet itself” (p.79). Yet, for Gaziulusoy (2015), contemporary design and innovation practices lack rigor when seeking to integrate sustainability science into new interventions towards sustainability, leaving behind vague claims about the potential for redesigning current linear systems. As such, innovative solutions tend to fall short in revealing the underlying interactions between socio-technical and socio-ecological systems necessary to transition to circular economies.

### 2.4. Community capitals

Flora et al. (2004) define capital as “any type of resource capable of producing additional resources” (p.165). They identify seven types of capital – natural, financial, manufactured, human, social, cultural, and political – that flow through socio-ecological systems at different rates, interact with each other, create synergies and contribute to sustainability. They created the Community Capital Framework (CCF), “to analyze community and economic development efforts from a systems perspective by identifying the assets in each capital [stock], the types of capital invested [flow], the interaction among the capitals, and the resulting impacts across capitals” (Emery and Flora, 2006, p.20). Through their interaction, properties and linkages emerge that may affect the sustainability of circular economy practices not only in the business ecosystem, but also in other realms of impact from economic activities. As this framing exposes correlations between the stocks and flows of the different capitals available within socio-ecological systems, it can also expose new opportunities for value creation, collaborations, partnership activation, and network connections.

While using multiple capitals to understand the dynamics of socio-

ecological systems is not new (for example, see Ashton and Bain, 2012; Mulrow et al., 2017), the CCF provides new possibilities for production and consumption systems to create and negotiate new types of values within more circular economic models. Researchers have applied the CCF either on processes of mapping assets or activities related to a single type of capital, or mapping how particular interventions impacted a capital of interest. In both situations, the CCF has become an effective descriptive tool to understand interventions that occurred in the past and shaped the contemporary situations being analyzed. Yet, intervening in complex socio-ecological challenges to transition towards sustainability requires more prescriptive use of the framework, and the development of more proactive tools and approaches.

## 3. Materials and method

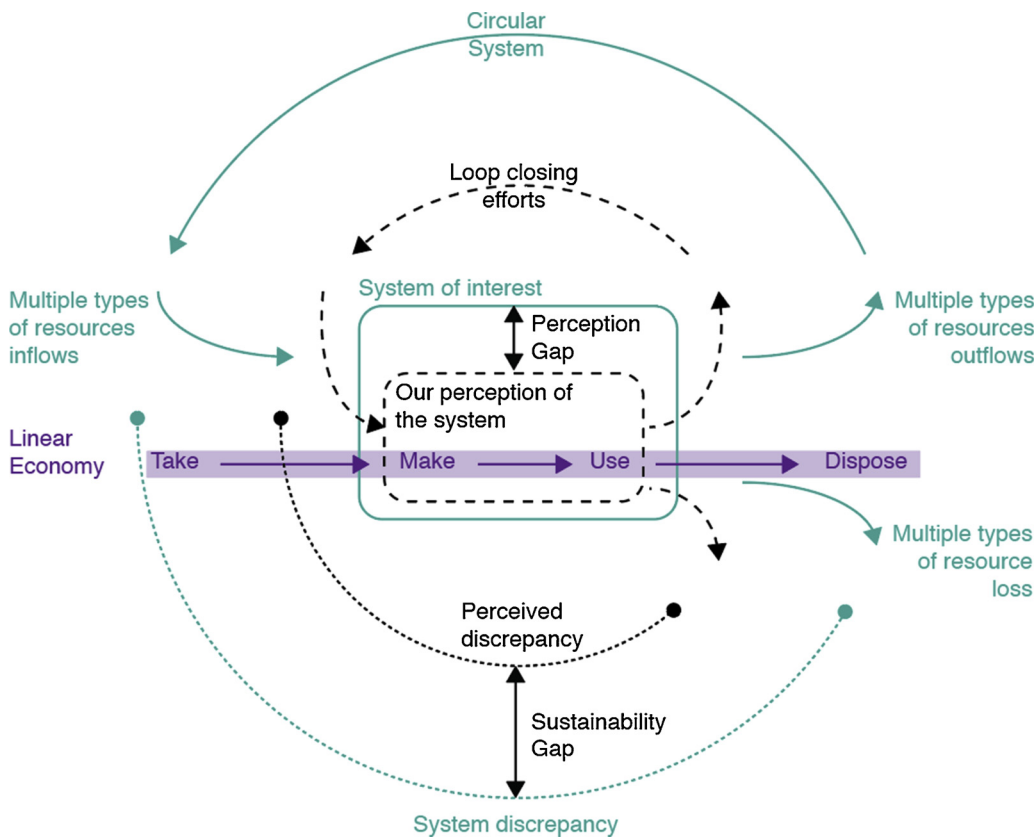
### 3.1. Framework: eight capitals as innovation lenses

While we may never fully understand a complex socio-ecological system in which a challenge is presented, we sought to expand our perceptions about it, by exposing different components, types of resources and their interactions. The circular economy intends to close loops through multiple strategies, but is limited as it considers too few resources in the perceived discrepancy of the system. A more holistic perception involves expanding not only the notion of the system itself, but also the incorporation of different types of resources that are flowing in it (see Fig. 1). We were interested in reducing the gap between the perceived discrepancy of the flow of resources (for example, by focusing only on materials) and the actual discrepancy (for example, by expanding the resources considered to include community knowledge and culture).

We wanted to explore how the Community Capitals Framework (CCF) could be used to understand the observed patterns of behavior in a system of interest, and to inform future interventions to increase the sustainability of socio-ecological systems. More specifically, we focused on examining how CCF can expand perception of the connectivity among multiple capitals that shape any given sustainability challenge, including exposing potential unintended consequences that result from new interventions. An eighth “digital” lens was added due to the contemporary role of digital technology and data in shaping innovation practices within multiple contexts. We asked ourselves “*how might we use the eight types of capital not only as a descriptive framework but also as a prescriptive tool to expand perceived opportunities and possibilities for intervening in socio-ecological systems?*” Each capital was framed as a lens through which researchers can map agents, their actions and interactions with that capital, and identify leverage points for intervention in a socio-ecological system. Examining the aggregated stocks and flows of the capitals allowed us to uncover resources that are drawn upon and altered through their interactions. Definitions of the eight capitals illustrate their roles in a system and are listed in Table 1.

### 3.2. Application: eight capitals as innovation lenses

This ongoing research is being carried out through mixed methods with action research as the primary methodology. Action research recognizes and reinforces processes of ‘learning by doing’ with a focus on developing practical interventions in complex challenges. The methodology has its foundations in the work of John Dewey, including his philosophical and theoretical contributions for more participatory and democratic processes of knowledge generation and dissemination (Lewin, 1946). Unlike natural science approaches, action research considers that knowledge is a social construct created within specific contexts, and that the actors embedded in these contexts have deep expertise about the space of problems being faced (Swann, 2002). Since the action of doing research brings with it a system of values, beliefs and criteria that shape choice-making, and therefore, both the outputs and outcomes of the research, action researchers recognize that



**Fig. 1.** How we perceive a system is defined by what we are focused on. As we attempt to create a CE, we recognize that there is a discrepancy between the linear flow of material resources and the efforts that are needed to close the loop. However, by expanding our view of the system, and the types of resources that are flowing we can broaden our perception of the system and the sustainability gap that exists between what we hope to achieve in the system that we perceive versus the complete complex system.

practical solutions have higher chances to succeed if researchers are involved in the context of application.

In order to apply the eight capitals as innovation lenses, we first identified a challenge and defined a system of interest through collaboration with a key partner. In 2016–2018, we developed three distinct collaborations at different geographic and organizational levels - facility (local circular economy at The Plant with partner Plant Chicago), city (food waste and sustainability in Chicago with partner the Chicago Food Policy Action Council), and region (Calumet regional regeneration with partner the Calumet Collaborative). Although the selection of these projects was made based on opportunities presented to the research team, all represent complex socio-ecological challenges with multiple agents, types of activities, use of multiple types of capital and positive and negative feedback mechanisms. We worked more intensively with one partner organization, but drew upon both our own and the partner’s network of collaborators to engage in the issues, engage diverse participants, and propose interventions in order to leverage the knowledge of different stakeholders distributed across these systems for a more sustainable outcome (McGinnis and Ostrom,

2014). We conducted the three projects considering the application of the innovation lenses framework to leverage and transform the knowledge and experience of actors into assets for advancing innovation practices oriented towards sustainability in these organizations. As such, we applied participatory action research (PAR) methodologies to co-create and co-disseminate knowledge with the partner organization, and relied on prototyping methods to integrate knowledge distributed across the network of actors embedded in the context being studied. PAR presented an alternative to traditional scientific methodologies, suggesting that research should be done within the context of application and in collaboration with actors involved in the situation of interest (Teram et al., 2005).

We then defined specific questions to uncover stocks and flows of the eight capitals in the relevant complex socio-ecological challenge (see Table 2). Though not extensive, these questions have provided a structure for uncovering and classifying information, as well as expanding stakeholders’ perceptions about the stocks and flows of available resources and assets within the socio-ecological systems in which they operate. The resulting innovation lenses framework, therefore, can

**Table 1**  
Definition of the Eight Capitals.  
(adapted from CCF/Emery and Flora, 2006).

<p><b>NATURAL</b> Comprises natural resources, both renewable and nonrenewable. It also includes fauna and flora, as well as their life supporting systems.</p>	<p><b>FINANCIAL</b> The productive power in the resources of other types of capitals. It includes the resources and assets of an individual or entity translated in the form of a currency that can be accessed, owned or traded.</p>	<p><b>MANUFACTURED</b> All material goods. It includes human-made elements such as physical infrastructures, roads, artefacts, and machines.</p>	<p><b>HUMAN</b> The ability and capability of individuals to produce, and manage their well-being. It includes individual health, knowledge, skills and motivation.</p>
<p><b>SOCIAL</b> The professional and the social connections among actors. It includes partnerships and collaborations, as well as informal gatherings.</p>	<p><b>CULTURAL</b> Values and beliefs inherent in social practices, or incorporated by communities. It also includes ethnicity, spirituality, heritage, traditions, and daily practices.</p>	<p><b>POLITICAL</b> Structure in organizations that determines how decisions are made and power is distributed. It involves hierarchy, inclusion, equity, transparency, access, and participation.</p>	<p><b>DIGITAL</b> Digital infrastructure and data. It includes digital platforms, as well as the mechanisms of data collection, analysis, and storage.</p>



**Table 2**  
Key questions for uncovering the use of stocks and flows of the eight capitals in a system of interest.

	NATURAL	FINANCIAL	MONEY	MANUFACTURED	HUMAN	WELLBEING
Fauna and Flora What is the composition of species?	Life support systems What is the composition and functions of energy, blue and green infrastructures?	Services What are the structures allowing for credits and loans?	What is the institutional structure defining value?	Infrastructure What is the infrastructure available and its condition?	Knowledge What are the institutional structures for knowledge creation and dissemination?	What are the institutions maintaining the capacity of individuals to perform?
How are species growth rates affected by various activities?	How and where are nutrients and components being extracted and regenerated?	How and where are financial services being provided?	How and where does the money flow considering the incomes and expenditures?	How and where are infrastructures being used?	How and where are the products and services being produced and consumed?	How is the capacity of individuals to perform defined?
SOCIAL Professional What is the portfolio of organizations? What are the values being exchanged?	Personal What are the structures promoting community engagement?	CULTURAL Local What are the traditions and cultural heritage? What values and beliefs sustain them?	Global What are global elements and practices that have been incorporated in the situation?	POLITICAL Regulations What are the policies influencing decisions?	Norms What is the power structure?	Data What are the mechanisms for data collection?
How and where are partnerships and collaborations being formed?	How and where are the events and activities supporting social gathering happening?	How and where are the (ordinary) practices and manifestations of the values and beliefs?	How and where are individuals and organizations being exposed to new global practices?	How and where are policies being enforced?	How and where are decisions being made?	How and where data is stored?

be considered a structure to map and understand the multiple types of resources and assets that are shaping complex socio-ecological challenges. The framework allowed us to raise different questions than traditional approaches, as well as to inform how underutilized and/or relevant elements could contribute to innovation for transitioning systems towards sustainability. Implicit in the application of these questions is the consideration of the role, and purpose of each asset in the system being explored.

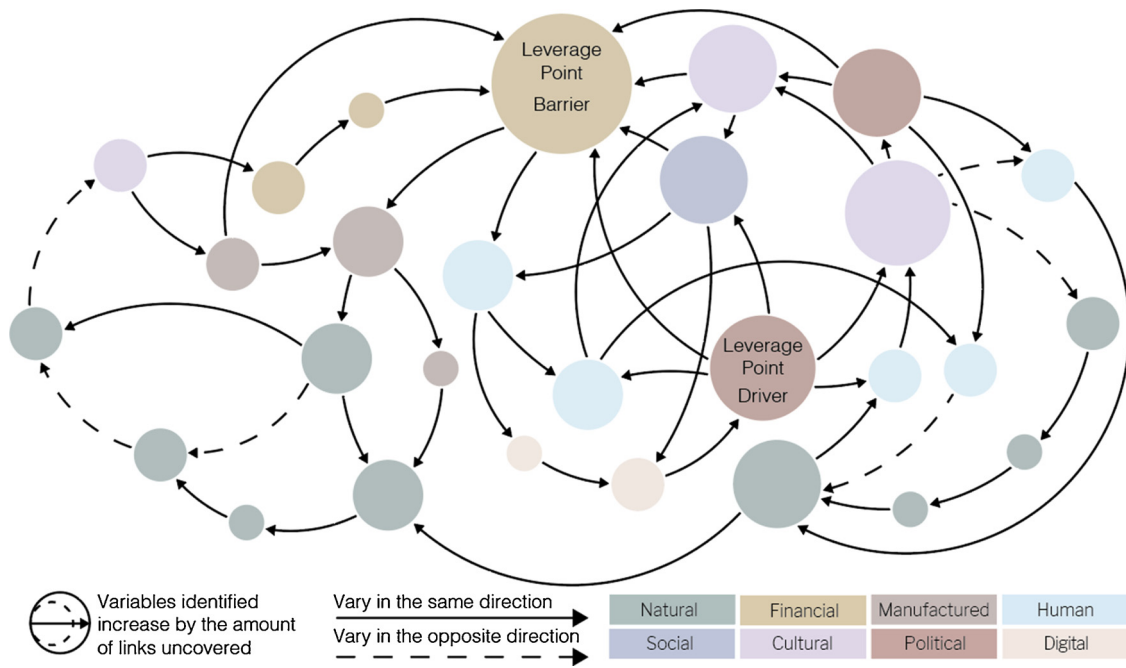
We applied the lenses to create systems dynamics maps in order to analyze and generate the interaction of multiple types of values, and “infrastructuring” new collaborations. As analytical lenses, they link human impacts to elements of social systems - from cultural values to political perspectives, institutional arrangements, and power structures, as well as impacts on ecosystems. As generative lenses, they can embed principles of sustainability into choice-making for new strategies, concepts and even features of future interventions. Furthermore, the application of the lenses can reveal dynamic behavior of the systems. By utilizing system dynamics maps to represent elements that can be increased and decreased (e.g. variables) considering the flows of multiple capitals, we have created visualizations that inform potential leverage points, considering barriers and drivers of interventions (Fig. 2). Once barriers and drivers of system’s change are identified, new places for intervening in the system can be explored (for example, the twelve leverage points proposed by Meadows, 1999).

The variables and leverage points identified in a system dynamics map are determined by the knowledge that the actors designing the map have about the socio-ecological challenge of interest and their own experiences. For these reasons, the systems maps are collectively built, so that assumptions being made by one actor can be validated by others. For the same reasons, the maps are continually changing given that our understanding of the dynamic interactions among various actors necessarily changes as we engage with more actors in the system and new information is gathered. The iterative nature of these exercises has expanded the perceptions of the actors about the systems in which they are involved, as well as our shared understanding about potential impacts, network effects, and consequences of future interventions.

### 3.3. Prototyping: eight capitals as innovation lenses

Prototypes are preliminary models of concepts used in a dialectic learning process in multiple domains. Design researchers use conceptual, visual and physical prototypes as ways to engage and involve actors, learn about the context, do research, test hypotheses and concepts (associated with products and knowledge), and explore alternative futures. These methods enables researchers to uncover fundamental issues in a defined problem through a collective diagnosis, as well as to integrate dispersed knowledge into the alternative solutions (Galey and Ruecker, 2010). The combination allows us to broker and integrate tacit, embedded and explicit knowledge from diverse stakeholders, into innovation practices that recognize and incorporate concerns of different types of capital for the circular economy. Tacit knowledge relates to the know-how and the experience of individuals operating on the micro level. Embedded knowledge relates to locked systemic routines, usually found in individuals’ and institutions’ daily operational practices at the meso level. Explicit knowledge relates to formalized and codified knowledge usually found in policies, academic papers, rules and regulations, books, and related documents traditionally incorporated as strategies in the macro level.

According to Cross and Roy’s (1989), unlike scientists who problem-solve by analysis, relying on ‘problem-focused’ strategies to advance their contributions, designers problem-solve by synthesis, therefore, relying on ‘solution-focused’ strategies to intervene in reality. As a practice-based discipline, synthesis in design might occur in and “be expressed as visual spatial knowledge in action” (Swann, 2002, p.55). Still, for actions to be relevant in research activities, they must be comprehensive and tangible, and it is there where prototyping methods



**Fig. 2.** Systems dynamics maps are a key tool in the framework, enabling the visualization of variables governing the flow of different types of capital, feedback between variables and drivers and barriers in the system. Barriers are represented by variables that have a large number of inflow arrows as they require multiple types of resources from different variables. Drivers are represented by variables that have a larger number of outflow arrows as they exert greater influence on other variables in the system.

contribute to providing evidence in research.

In this research, prototyping methodologies were applied for collecting evidence through the application of the innovation lenses (Fig. 3). In all of the projects, we prototyped new tools and methods to codify data gathered, including contributions and participation from multiple actors involved in each one of the cases, as well as to support ideation for interventions. Below we describe one of the cases in more detail: leveraging brownfields as underutilized assets for sustainable (re)development of the Calumet region. It is important to note that as design methodologies are iterative, there is not a hard distinction between methods and results, both are simultaneously realized, as such the results presented include the development of prototyping methods.

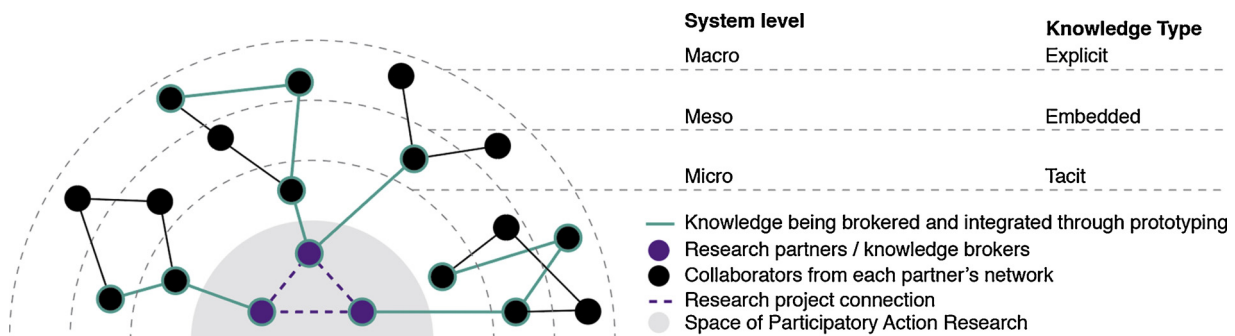
#### 4. Results and discussion

##### 4.1. Calumet region

The Calumet region encompasses the southeast side of Chicago and southern Cook County in Illinois and northwestern counties (Lake, Porter, LaPorte) in Indiana in the midwestern United States. The bi-state Calumet region boasts proud and diverse communities, important

natural ecosystems, and a powerful industrial heritage. Because of its strategic position in the country's geography, the region has been the industrial heart of the Midwest, attracting high investments that relied upon easy access to transportation, open spaces, and the presence of skilled workers (Sellers, 2006). During the twentieth century, prioritization of economic growth over environmental sustainability and social equity led to both high level of pollutants from industrial effluent and waste as well as exclusion of large segments of the local population from economic and political benefits (Reese, 2016).

By the early 2000s, industrial production activities declined or moved away, leaving behind large swathes of vacant and contaminated land that lacked economic activities, business interest, and social capital (Sellers, 2006). This post-industrial legacy became apparent in the declining livelihood of the region as a whole because the presence, or perceived presence, of hazardous effluents and materials, combined with the reduction of job opportunities, prompted residents to move out of the Calumet area (Reese, 2016). While some of vacant spaces are clean parcels or former agricultural land (e.g. greenfields), many others contain multiple levels of contamination (e.g. brownfields) and can blight not only their immediate surroundings, but also negatively impact the future of the entire region. Thus, after years of disinvestment, a



**Fig. 3.** We utilized a Participatory Action Research framework to broker and integrate tacit, embedded and explicit knowledge from diverse collaborators, including community leaders and subject matter experts, through the use of prototypes in different steps in the project.

patchwork of brownfields became a significant barrier for promoting sustainable redevelopment of the region. Reinvigorating post-industrial regions like the Calumet will become increasingly important for realizing thriving local circular economies on a grander scale (Ashton et al., 2017).

Brownfields redevelopment typically follows a very linear path - first funding is secured, the site is surveyed for contaminants, a remediation plan is created and implemented; once cleaned, the site becomes available for redevelopment and productive use (EPA, 2018). The redevelopment process is often led, funded, and implemented by organizations, developers and advocates that are significantly disconnected from the daily lives of community members. As a result these approaches cause significant unintended consequences, such as disruption of local economies and gentrification, further disenfranchising poor, long-time residents. Moreover, many of these consequences are not foreseen because the focus on individual sites prevents a broader, systemic view.

By only focusing on regenerating natural, financial, and manufactured capitals, the disruption of local practices and the degeneration of other types of capital will continue to be replicated across the region. However, we hypothesized that if agents could recognize that there are multiple resources circulating during redevelopment processes, then advances on operational and technical processes for remediating brownfields could explore alternative pathways to address the systemic impact in the immediate surroundings of the sites.

#### 4.2. Application of eight capitals to Calumet region

The “Future of Brownfields” is an ongoing collaboration between two units at the Illinois Institute of Technology - the Institute of Design and the Stuart School of Business in collaboration with the Calumet Collaborative, a bi-state non-governmental organization (NGO) dedicated to achieving inclusive regional prosperity and improving the quality of life in the Calumet region through sustainable development. The NGO catalyzes innovative partnerships between Illinois and Indiana stakeholders to advance a thriving Calumet region with a focus on (1) Livable Communities, (2) Economic Opportunity, (3) Environment, (4) Culture and Heritage (Calumet Collaborative, 2018). The research explores the region as a patchwork of situated issues, shaped by the intersection of multiple resource flows, and focuses on brownfield redevelopment as a critical path for regional regeneration through local circular economies.

##### 4.2.1. Approach

Our team took a nonlinear, design-led approach to understand the redevelopment processes of brownfields. During the first phase of the project (November 2017 - May 2018), we applied the innovation lenses across three steps: sense making, reframing, and envisioning, each using prototyping as a method for exploration (Fig. 4). We prototyped several interventions, eventually proposing five strategies capable of informing alternative pathways for brownfield redevelopment that would lead towards circular economies.

Instead of embracing the entire region, we first identified several patterns among brownfields in the Calumet Region, focusing on four archetypes: vacant residential buildings, abandoned industrial sites, former landfills, and contaminated natural areas. Each archetype was researched as a system in itself, so that dynamics happening across different levels of each archetypal system could also be considered. We explored brownfields not just as problems of contaminated and unproductive land but as sites where multiple systems intersect - such as housing, environmental protection, public safety, education, mobility, insurance, public health, zoning, among others. In each of these systems, underutilized assets in the regions were identified, and prototyping methodologies were used to explore how they could be (re) activated to restore local economies considering the circulation of the previously identified resources. This framing allowed us to question

traditional models of remediation processes by focusing the intervention not only on the remediation, but on the redevelopment process itself. From this perspective, remediating the sites was understood as a critical step, but not the end goal for creating new opportunities and possibilities to establish local circular economies.

**4.2.1.1. Step 1: sense making.** The ‘sense making’ step included secondary research, semi-structured interviews with subject matter experts, site visits and observation. We utilized several design methods, including site and user observation, five stages of human experiences, five human factors, POEMS (people, objects, environment, messages, and services), as well as value webs, activity systems, ERAF (entities, relations, attributes, and flows) systems maps, among others (for details on design methods, see Kumar, 2012) to gather and organize information. These were used in combination with systems dynamics and the innovation lenses to map how the circulation of different types of resources hinder or support current brownfield redevelopment processes.

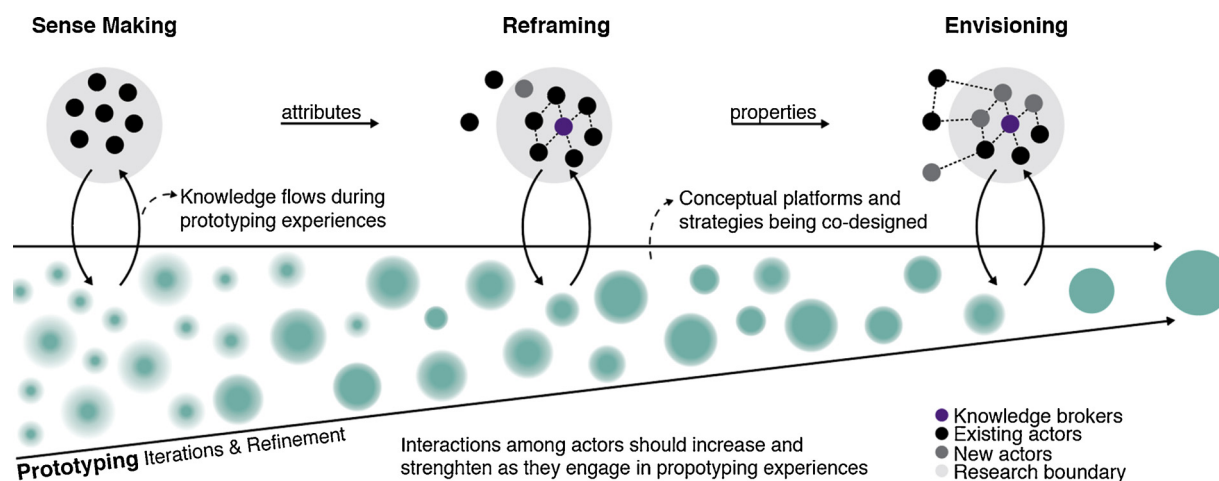
To complete this step, an interactive workshop was held with community leaders in the region and subject matter experts from various fields, including strategy design, economic development, urban planning, data mining, product and service design, among others. The system dynamics maps were used as prototypes to validate assumptions, identify bias, and explore potential interventions for brownfield redevelopment.

Participants in the workshop were selected based on their experience with brownfields and their expertise in mobilizing specific capitals during redevelopment processes. Beside their technical and capital expertise, (1) diversity in demographic representations (e.g. gender, ethnicity), (2) institutional representation, including sectors (e.g. public institutions, private sector companies, NGOs, and academia), organizational role or rank (e.g. directors, managers, analysts, etc), (3) state representation (Indiana or Illinois), and (4) personal experiences and backgrounds were also considered valuable contributions that directly or indirectly inform the design of future interventions. While no structure is able to represent the holistic contribution each individual can bring, having multiple criteria for articulating the overall composition of participants was critical for a priori identification of deficits and overlaps, and for supporting strategic decisions about who should be recruited, and why. Lastly, invitation of participants was done by identifying actors within the network of collaborators of each partner organization, and the strategic extension of these invitations to the collaborator’s own networks. In Table 3, we present the structure used to map the participants in all workshops and prototyping activities of the first phase of this project.

The integration of data gathered during sense-making activities, including knowledge brokered during prototyping, led us to four attributes influencing dynamics at the macro or strategic level that are preventing transitions towards local circular economies in brownfield redevelopment: *centralization of power, isolation and fragmentation of external investment, limited perception of multiple values in systems, and lack of accountability and ownership of redeveloping brownfields by local residents*. These attributes provide new references for undertaking systems change.

**4.2.1.2. Step 2: reframing.** The second step was dedicated to ‘reframing’ the challenge of brownfields. Focusing on the previously identified system attributes at the macro level, we reframed our research explorations: “How might we ‘decentralize’ governance in neighborhoods? How might we retain external investments to scale existing efforts? How might we generate multiple types of values from blighted sites? How might we connect local residents to the environment?” While open ended, these questions reflect some of the fundamental challenges that are preventing local circular economies to be established within the Calumet region.

The reframing step was also structured around prototyping



**Fig. 4.** Phase 1 of the “Future of Brownfields” project involved three steps - sense making, reframing and envisioning utilizing participatory action research and prototyping. The results of each step refined the prototypes being developed through consultation and co-creation with participants, leading to five strategies.

activities with community leaders and subject matter experts. Unlike in the first step, participants were involved in generative activities rather than prescriptive ones. Workshops and fieldwork were centered around the four questions, and participants were encouraged to explore new models of engagement and redevelopment practices at the micro level that could respond to the dynamics of the different capitals shaping brownfields. We identified several properties in the dynamics happening at the micro level that could potentially inform future strategies for each archetype identified in step one (Fig. 5). We present them as four actionable properties, that is key features that should be included in any intervention at the micro-level: *self-organizing systems (vacant residential buildings)*, *values creation (abandoned industrial sites)*, *symbiotic relations (former landfills)*, and *adaptive growth (contaminated natural areas)* (Nogueira and Teixeira, 2018a).

Self-organization means recognizing and building on autonomous efforts to develop local solutions, such as block clubs, where local residents work together to improve their surroundings. Symbiotic relations refers to collective efforts to use resources (particularly wastes) more effectively, such as industrial symbiosis arrangements (Chertow, 2000; Chertow et al., 2008). Values creation refers to a holistic approach to defining value by considering interdependencies among local actors, such as the recognition or creation of local market places, including informal economic transactions. Lastly, adaptive growth refers to a type of growth in which actors gradually become better suited to their environment, for example urban agriculture initiatives are rebuilding a narrative of the connection of communities of color with land and food growing, in order to increase economic empowerment in those communities (see Urban Growers Collective). These are not meant to be exhaustive, rather an indication of what’s possible given the underutilized assets identified, and the common challenges in brownfields redevelopment (Fig. 6).

**4.2.1.3. Step 3: envisioning.** The last step consisted of ‘envisioning’ strategies for the Calumet region by speculating platforms and systems’ intervention through which brownfield redevelopment could lead to circular economies. We started the last step by developing conceptual platforms for intervening in each archetype considering these four properties. We co-created four conceptual platforms through

three rounds of prototyping. For each round, different participants were invited, and the team iterated and refined the concepts between activities considering previous experiences, suggestions, and critiques. The concepts were always introduced to the participants through prototypes of artifacts, scenarios, short descriptions, storytelling and visualizations, including system dynamics maps with the innovation lenses. By proposing these concepts, we were able to integrate the different dynamics shaping one archetype into interventions for another. This horizontal integration of the archetypes served as a mechanism for uncovering seemingly unrelated interactions, identifying new opportunities for more holistic strategies that account for the multiple dynamics happening across the region, currently distributed across different archetypes.

After the three rounds of prototyping the conceptual platforms, we ran a final co-creation workshop with community leaders and subject matter experts so that their knowledge could be integrated into new features of each platform. This exercise captured considerations of multi-level efforts currently distributed across different systems, such as community building, job creation, new financing models, and policy making and implementation into new strategies for CE transitions

Through the prototypes, participants quickly realized that although fundamental, the traditional approach for brownfield redevelopment was insufficient for regional regeneration towards circular economy. The application of the innovation lenses enabled them to understand several dynamics that were not previously considered, consequently recognizing the need for new engagement models and new types of values to be exchanged among stakeholders. Five strategies were proposed for valuing multiple resource flows in order to build a circular economy in the region (Nogueira and Teixeira, 2018b):

- 1 **Empower science** - increasing local leadership capacity in applied scientific research so that new means for tracking and understanding interactions between socio-technical and socio-ecological systems can inform alternative evidence-based decision-making processes;
- 2 **Involve residents** - incorporating local dynamics of daily lives into interventions at any given system, including making ethical choices for preventing the displacement of people;
- 3 **Leverage assets** - unlocking the potential of existing initiatives in the

**Table 3**  
Example of structure to strategize the composition of participants in workshop and prototyping activities.

Individual			Institution					Add. info.
Name	Gender	Ethnicity	Organization	State	Sector	Role	Capital	Personal exp.



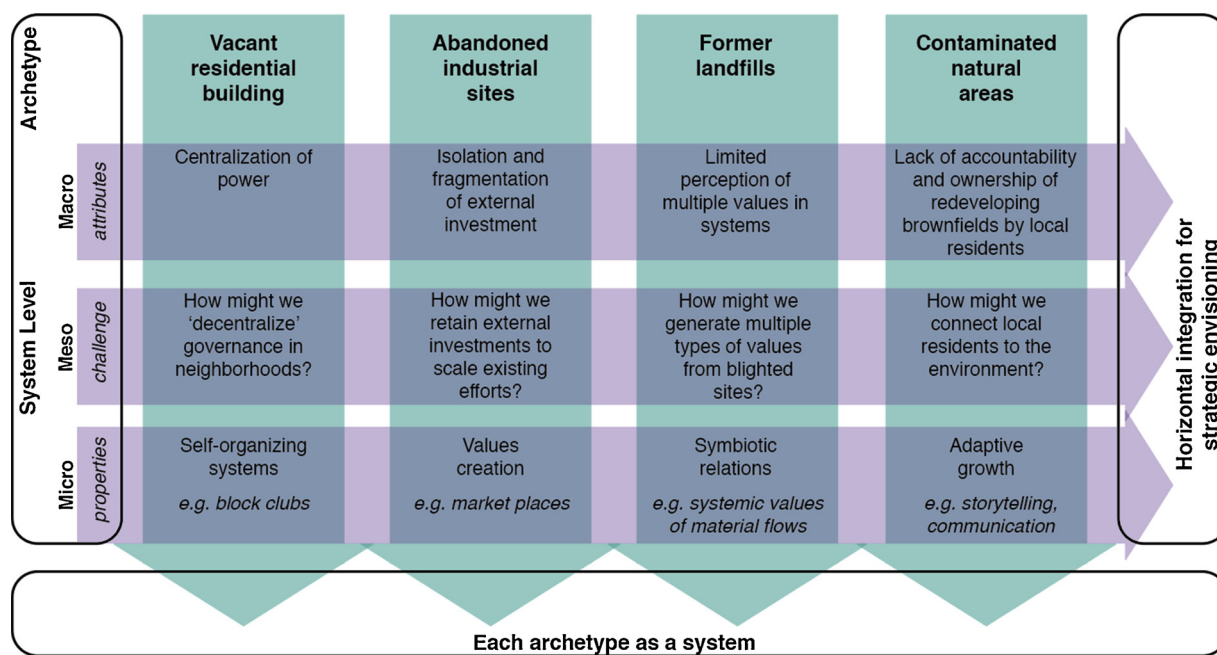


Fig. 5. Archetypes, attributes and properties that were surfaced through the prototyping activities in the Future of Brownfields project.

region, as well as uncovering underutilized resources that could be activated for transitioning towards circular economy;

- 4 **Strengthen local economy** - recognizing economic activities and ambitions of local residents in order for them to directly benefit from and take ownership of new activities;
- 5 **Build integrated infrastructure** - integrating the hard (tangible) and soft (intangible) dimensions of existing and new infrastructures to unlock current linear and fragmented practices.

These strategies were used to inform the second phase of the Future of Brownfields project (May 2018- August 2018), which focused on prototyping three concrete interventions that contribute towards local circular economies (Hodges, 2018). The first, Flag Calumet, was a collectively built modular art installation that also gathered data about environmental conditions to increase local residents understanding of and connection with the local environment. The second, Mini Calumet, was a simulation game designed to support local youth to explore alternative governance systems capable of dealing with the socio-ecological challenges of the Calumet region. The third, Act Calumet, was a digital platform for civic empowerment that mediates interactions among residents to optimize local resources. In its third phase (September 2018- December 2019), the collaboration advanced these micro-pilots by iterating and refining the infrastructures prototyped in phase two, and co-designing alternative models for scaling up implementation and impact.

Fig 6 presents a simplified version of the system dynamics map with the different variables clustered by the strategies proposed in the final workshop. These variables could be used as indicators of system change as the region transitions towards CE.

5. Conclusions

Transition towards the circular economy requires an expanded perception of systems in which individuals and organizations are embedded and the articulation of new values representative of the diverse needs of the multiple stakeholders interacting in these systems. Yet, when different stakeholders come together to collaborate towards interventions, they bring different experiences, including worldviews and different types of knowledge about the same system. This increases the complexity for creating concrete interventions to transition from

current linear practices towards more circular ones because each party will also have a specific interests and a unique understanding about how potential interventions should be designed and implemented. Without an appropriate toolkit and methods for making sense of the multiple types of flows shaping linear dynamics within complex socio-ecological challenges, collaborations might continue to aim at transitioning towards more circular systems, but remain centered on traditional actions and agendas.

Rather than strictly focusing on natural, financial and manufactured capital, the use of eight capitals as innovation lenses presents a structure for making sense of distributed complexity and increasing ambiguity considering different types of resources shaping linear dynamics in a given system. It does so by 'infrastructuring' potential collaborations that recognize the interconnectivity between socio-technical and socio-ecological knowledge for the design of innovative CE practices. As a result, the framework enables new questions to be raised, consequently supporting different stakeholders (including researchers) to uncover their own hidden assumptions about how to intervene in linear practices, and surfacing unconsidered barriers affecting the circulation of various types of resources flows. The framework has potential to (1) amplify participants understanding of the dynamic interactions of multiple types of capital shaping the situation in which they are embedded, (2) expand the opportunities for integrating the socio-technical and the ecological systems into innovative approaches in a CE, and (3) provide new possibilities for systemic interventions for transitioning towards CE.

As innovation lenses, the eight capitals have much to explore regarding representations of variables used to manage and measure the different resources in socio-ecological systems. One of the challenges, for example, is the ambiguity in definitions of what constitutes particular classes of capitals, particularly the social, cultural, and political and their interactions. Moreover, the framework does not provide clear paths for intervening in systems, rather suggestions for how to bring diverse stakeholders and their disparate knowledge and experiences to inform possible interventions. However, by incorporating considerations of systems thinking and utilizing design methods, including prototyping, new types of values can be recognized through the application of the framework. For example, a more diverse, local, and inclusive group of stakeholders can be integrated into innovation processes for transitioning towards the circular economy. Yet, since the use and

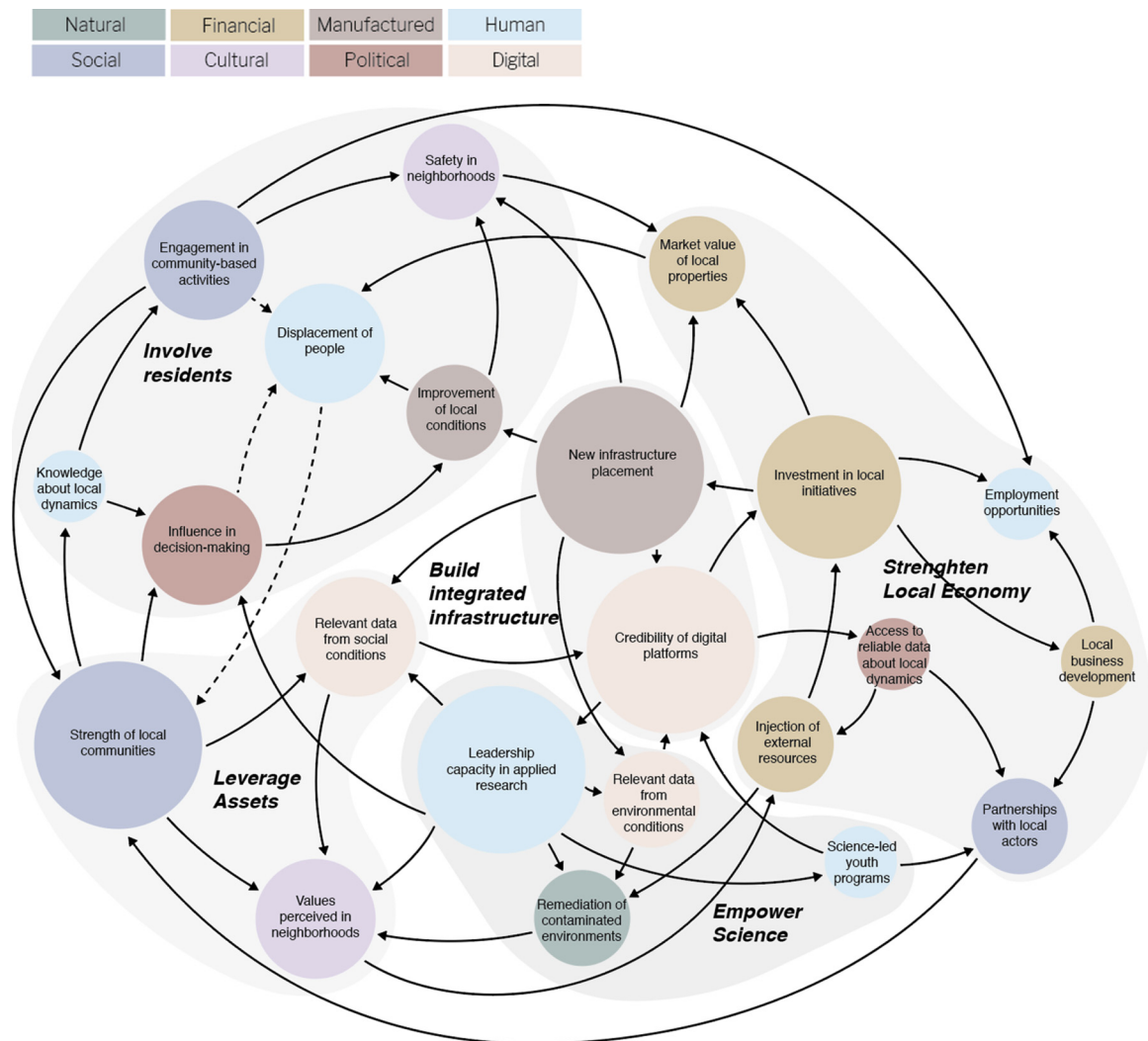


Fig. 6. Simplified systems dynamics map for new strategies to transition to circular economies in the Calumet region, building on brownfield redevelopment process, and created through the three steps of the prototyping process.

comprehension of the capitals is context sensitive, the establishment of variables to be measured, and system’s properties to be managed varies from challenge to challenge, and from situation to situation.

Aligned with the above reasoning is the notion that transition towards circular economy requires dynamic, alternative approaches to systemic interventions. It is unlikely that traditional linear, and fragmented step-by-step process will provide the structural transformation necessary to enable circular flows of different types of capitals. As a non-linear, systemic process, prototyping presents a design-led research approach that is collaborative, participatory, and context dependent. For this reason, it is expected that the outputs and outcomes from such approach will differ depending on who is involved in the process, and the shared knowledge that is generated in the process. While the results are not replicable, and have only been applied with a few cases, the approach and methods can be because we have been able to adapt accordingly to the interests of different partner organizations operating in different levels of socio-ecological systems through the development of a playbook (Nogueira et al., 2018). Still, how this playbook is utilized by other researchers and practitioners, as well as the evidence of their impact will be relevant indicators of its applicability for the CE transition.

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