26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

Integrated Community Resilience, A Model Based Systems Engineering Approach

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Agenda

- Community Resilience Architecture
- Systems Engineering Process
- Systems Engineering Framework
- Human Capital Model
- Conclusions & Continuing Study

Human Capital Modeling

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Application of **systems engineering** and **systems thinking** to public policy and program development/evaluation

Process:
Sociotechnical Systems analysis reflecting measures/metrics from disparate sources and assessed at disparate scales (visualizing levels of abstraction or aggregation)

- Linking **System** & **Context**
- Evaluating **System Constructs**
- Modeling System **Behaviors**

Outcomes:
models reflecting the complex relationships in and cascading impacts of [local-, state-, regional-, or national-] level institutional decisions

Formal evaluation of measures/metrics against a common set of **system constructs** used to assess merits and impacts of proposed policy/programs

Community Resilience Context – It's About People

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➢**MOORE, OKLAHOMA**: On May 20, 2013, an EF5 tornado struck Moore, Oklahoma, a suburb of Oklahoma City. 24 were killed and 377 injured. Two years later, *Moore had been mostly restored*.

- "Places like Moore are attached to metropolitan areas, and there are jobs and businesses to run. And then there is infrastructure." (Johnson 2015)
- Moore has a 25% higher median household income and 10% higher median home prices than state average (City-Data.com)


Tornado destruction through Moore, OK

➢**CORDOVA, ALABAMA:** On April 27, 2011 a large tornado struck the rural town of Cordova, Alabama, killing 3 people. Two years later, after tragic examples of poor local governance and bureaucratic delays, *downtown Cordova began to gradually rebuild*.

- "A good surprise has been the overall spirit, dedication and forward thinking goals of the citizens of Cordova." (Harding 2012)
- Cordova's median household income and median home prices are less than half the state average (City-Data.com)


Downtown Cordova, AL after the 2011 tornado

Dynamic Process of Community Resilience

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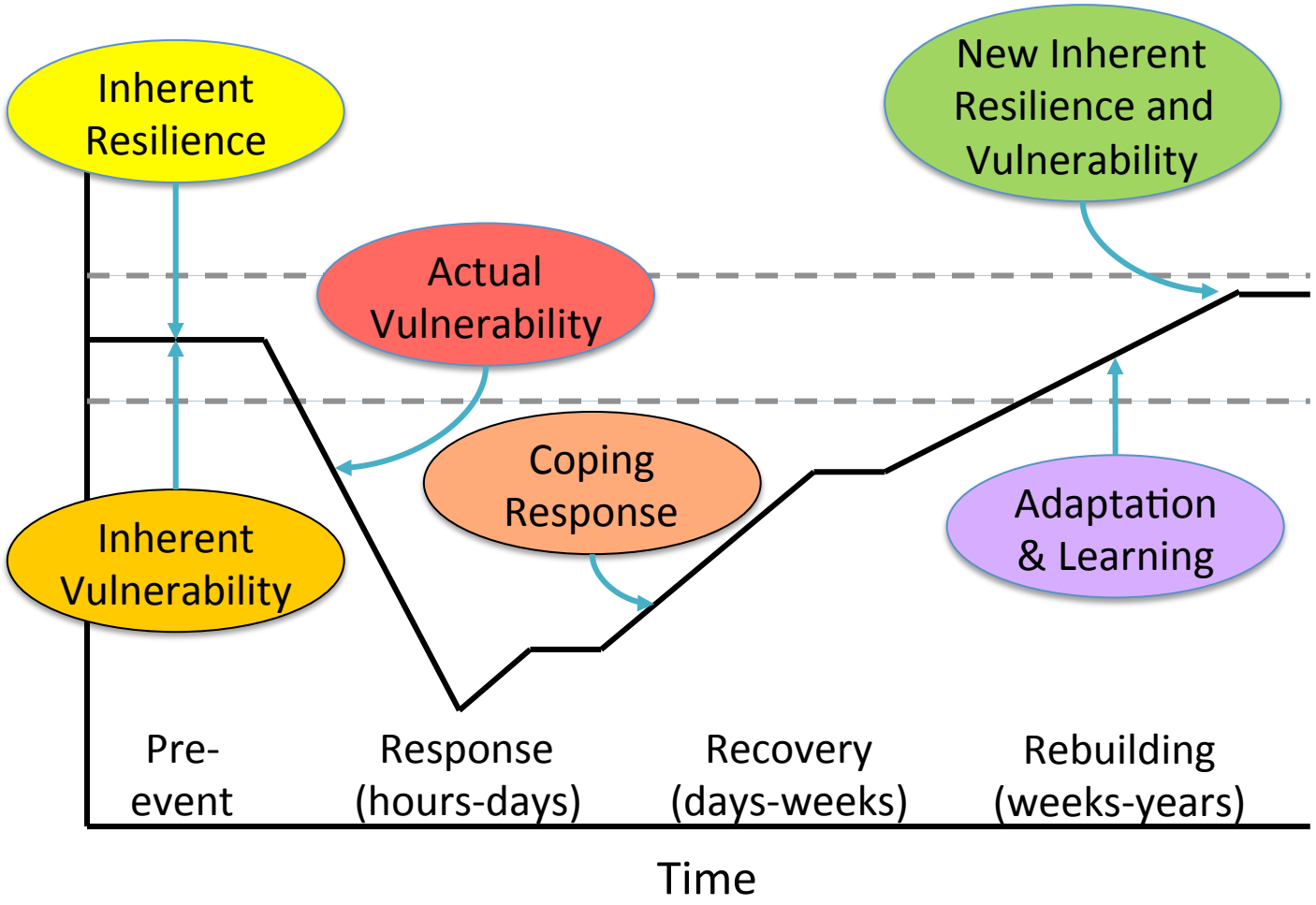

A primary measure of ***resilience*** is the number of people and businesses that are ***not displaced***

(Sources: Cutter 2008, Miles & Chang 2006)

Human Capital Model

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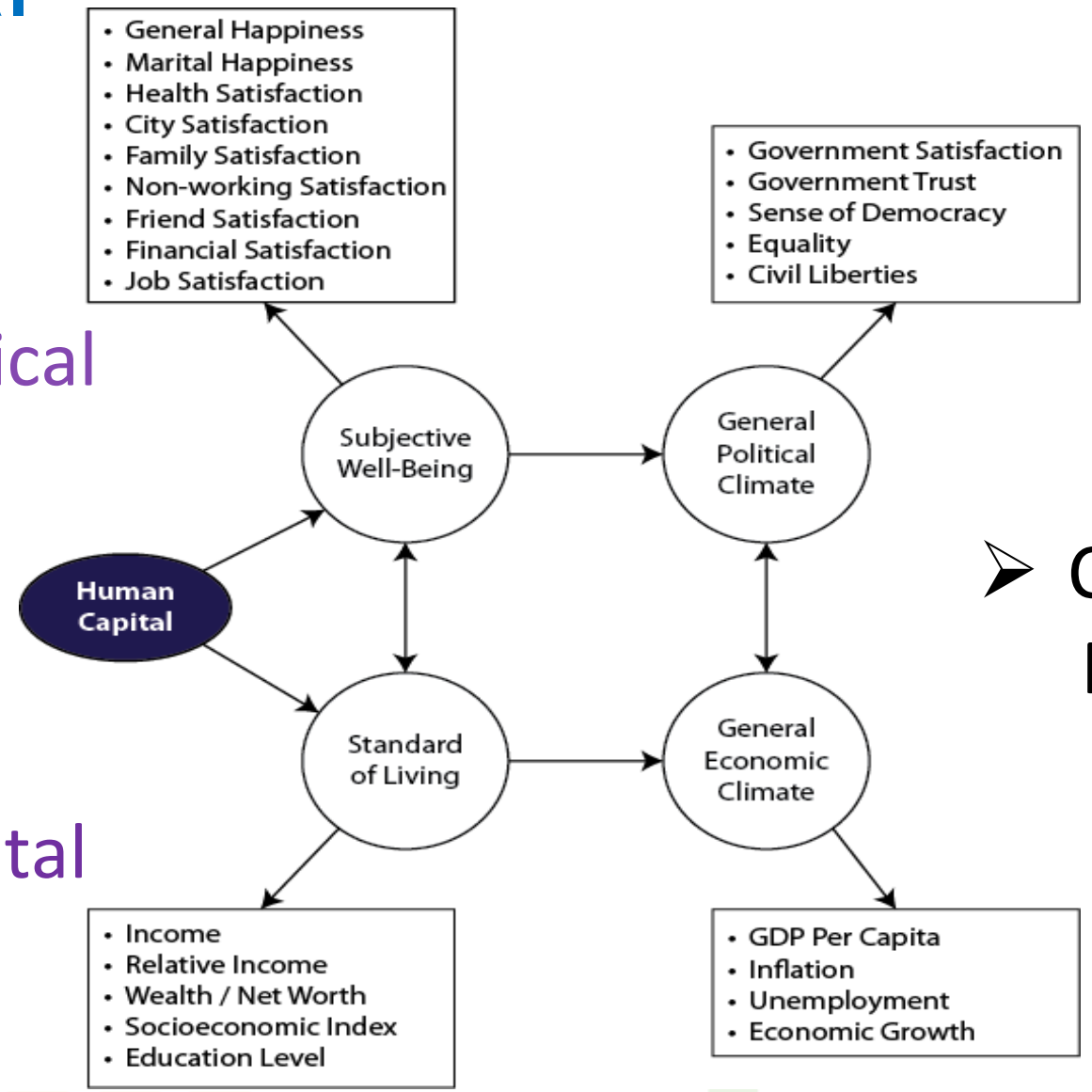
- Psychological Factors
- Socio-Environmental Factors
- Contextual Factors

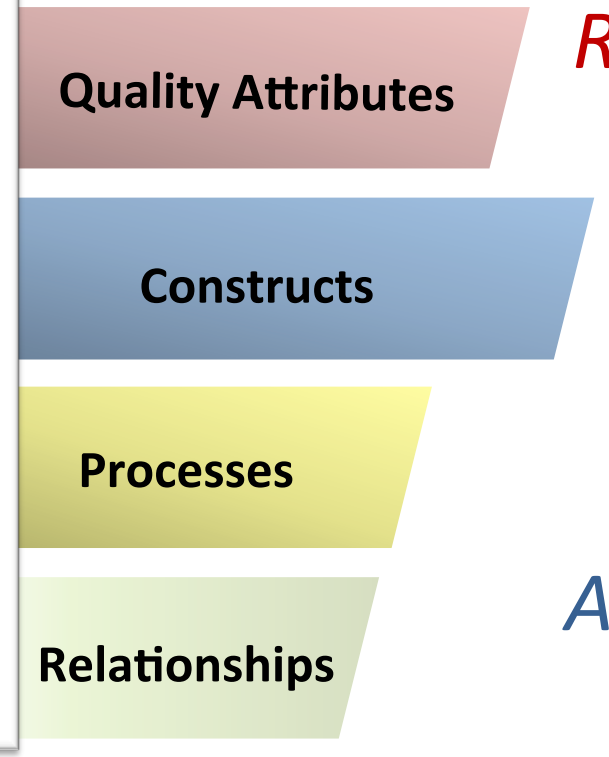


Community Vulnerability & Resilience

(Source: Folds 2008)

System Constructs

- System constructs are explanatory variables that aggregate lower level measurable causal variables
- Consisting of aggregated measures of observable elements that have a causal relationship to the construct
- Represent the components of the system of interest and also related components of the context in which the system is observed



Resilience
Sustainability

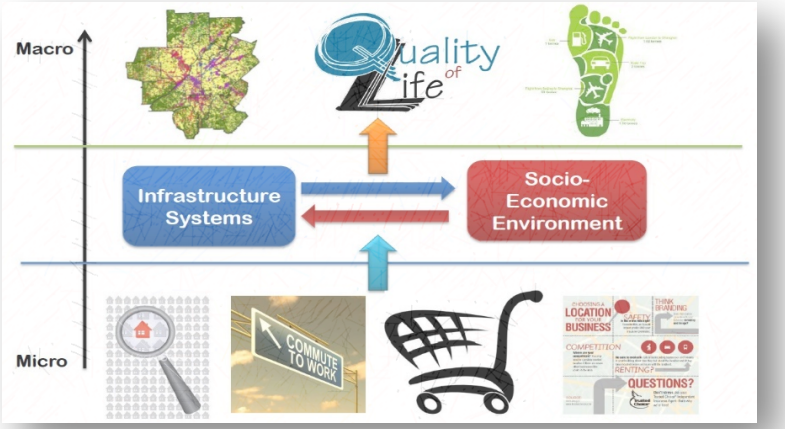
Standard of Living
Subjective Well-Being
Equality *Quality of Life*
Autonomy *Empowerment*
Environment

Requires long-term management of a data model and structural architecture that reflects the aggregation and abstraction of common system and context variables in an appropriate set of relationships

Model Urban Systems (MUST)

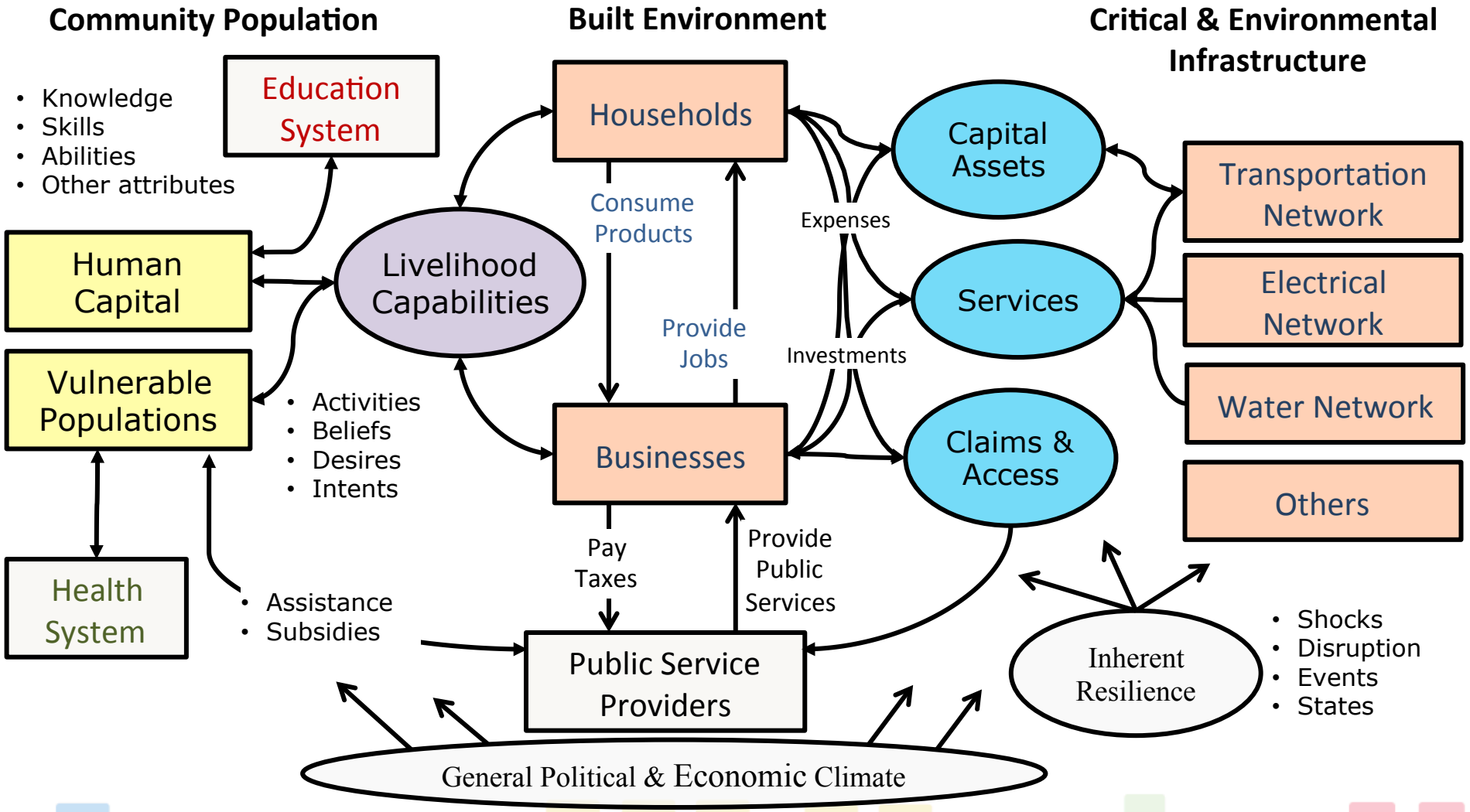
US National Science Foundation project: Resilient Infrastructure Processes and Services (RIPS)

- Postulates that interconnected and decentralized infrastructure systems are more resilient than isolated and centralized infrastructure via **increased response diversity** and **more sustainable resource use**
- Considers performance and function of **Water**, **Energy**, and **Transportation** systems working together as a whole, and in the context of **social**, **behavioral**, and **economic** decision-making
- Integrates models of **human capital**, **societal networks**, and **institutional support** with models of **physical infrastructure**, **economics**, and **resource flows**



(Crittenden, NSF project 1441208)

Structural Architecture of Community Resilience – the Six Capitals



Legend

- Human Capital
- Social Capital
- Institutional Capital
- Financial Capital
- Physical Capital
- Natural Capital

Agenda

- Community Resilience Architecture
- ➢ Systems Engineering Process
- ➢ Systems Engineering Framework
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Sociotechnical Systems of Systems

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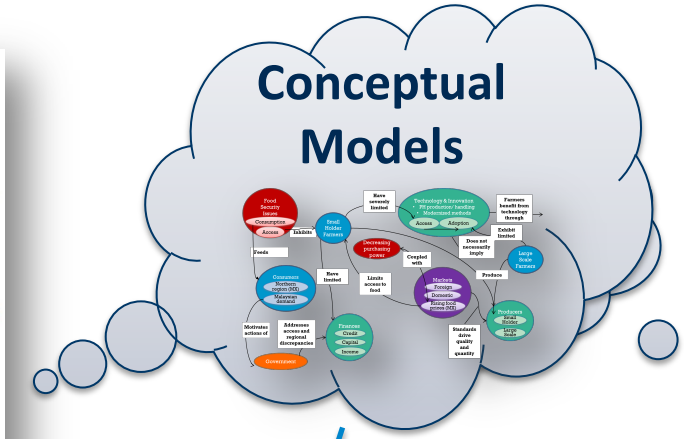
Multi-Layer Context Analysis



State Variables

Object Models

Qualitative Methods

Boundaries and Abstractions

Entity-Relationships

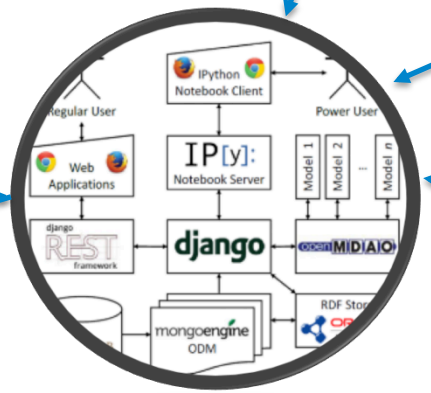
System Constructs

Human Sense-Making

Evaluative

Machine Decision Analytics

Predictive



Processes & Behaviors

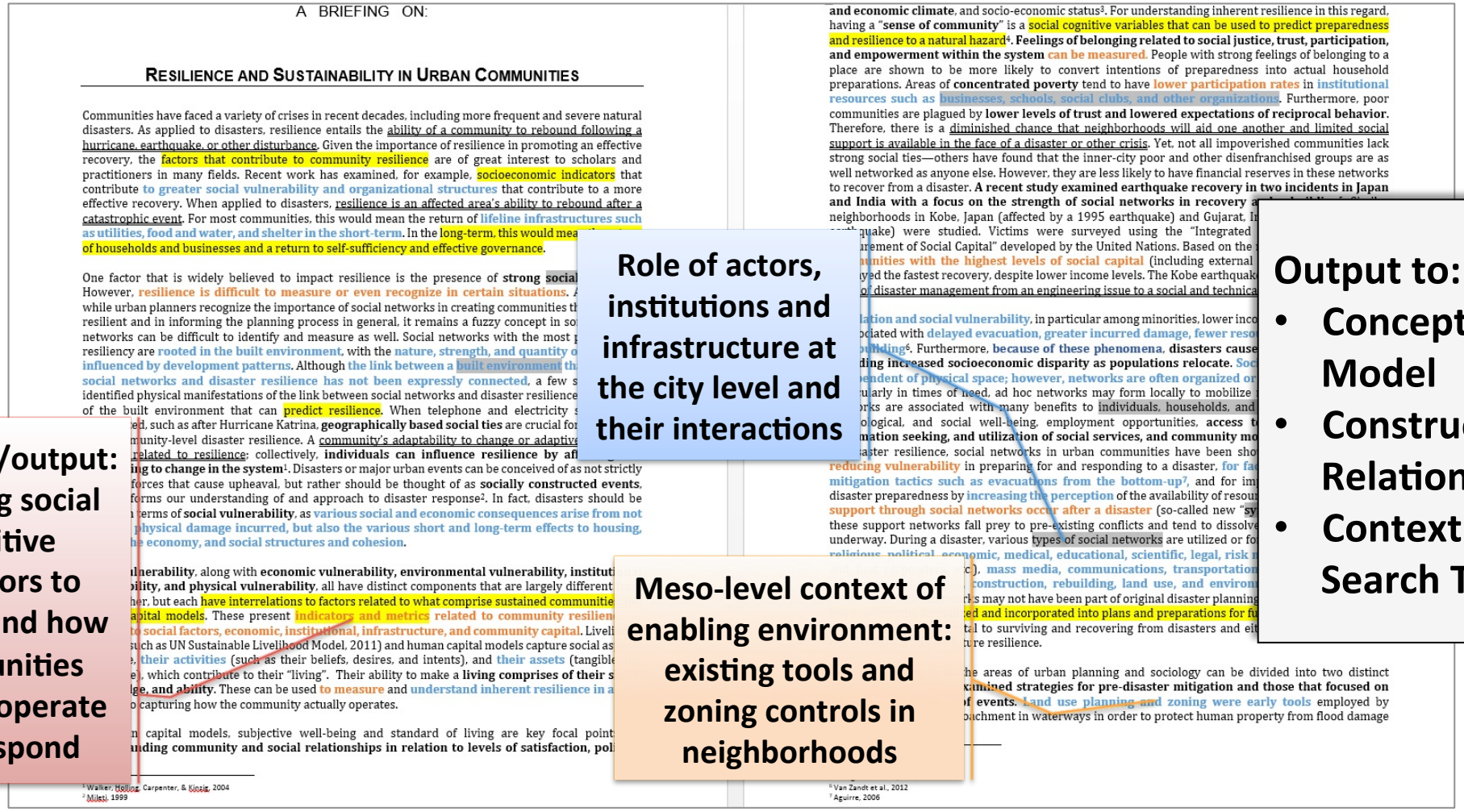
Dynamic Models

Equations

Analytical Methods

Systems Engineering Framework

Context Development Narrative



A BRIEFING ON:

RESILIENCE AND SUSTAINABILITY IN URBAN COMMUNITIES

Communities have faced a variety of crises in recent decades, including more frequent and severe natural disasters. As applied to disasters, resilience entails the ability of a community to rebound following a hurricane, earthquake, or other disturbance. Given the importance of resilience in promoting an effective recovery, the factors that contribute to community resilience are of great interest to scholars and practitioners in many fields. Recent work has examined, for example, socioeconomic indicators that contribute to greater social vulnerability and organizational structures that contribute to a more effective recovery. When applied to disasters, resilience is an affected area's ability to rebound after a catastrophic event. For most communities, this would mean the return of lifeline infrastructures such as utilities, food and water, and shelter in the short-term. In the long-term, this would mea
of households and businesses and a return to self-sufficiency and effective governance.

One factor that is widely believed to impact resilience is the presence of **strong socia**
However, resilience is difficult to measure or even recognize in certain situations. A
while urban planners recognize the importance of social networks in creating communities th
resilient and in informing the planning process in general, it remains a fuzzy concept in so
networks can be difficult to identify and measure as well. Social networks with the most
resiliency are rooted in the built environment, with the nature, strength, and quantity o
influenced by development patterns. Although the link between a built environment th
social networks and disaster resilience has not been expressly connected, a few s
identified physical manifestations of the link between social networks and disaster resilience
of the built environment that can predict resilience. When telephone and electricity
ed, such as after Hurricane Katrina, **geographically based social ties** are crucial fo
munity-level disaster resilience. A community's adaptability to change or adaptive
related to resilience; collectively, **individuals can influence resilience by af**
ing to change in the system[1]. Disasters or major urban events can be conceived of as not strictly
forces that cause upheaval, but rather should be thought of as **socially constructed events**,
forms our understanding of and approach to disaster response[2]. In fact, disasters should be
terms of **social vulnerability**, as various social and economic consequences arise from not
physical damage incurred, but also the various short and long-term effects to housing,
he economy, and social structures and cohesion.

lnerability, along with **economic vulnerability, environmental vulnerability, institut**
bility, and physical vulnerability, all have distinct components that are largely different
her, but each have interrelations to factors related to what comprise sustained communitie
apital models. These present indicators and metrics related to community resilien
to social factors, economic, institutional, infrastructure, and community capital. Liveli
such as UN Sustainable Livelihood Model, 2011) and human capital models capture social as
, their activities (such as their beliefs, desires, and intents), and their assets (tangible
e), which contribute to their "living". Their ability to make a **living comprises of their s**
lge, and ability. These can be used to measure and understand inherent resilience in a
o capturing how the community actually operates.

n capital models, subjective well-being and standard of living are key focal point
nding community and social relationships in relation to levels of satisfaction, pol

[1] Walker, Holling, Carpenter, & Kinzig, 2004
[2] Miletti, 1999

and economic climate, and socio-economic status[3]. For understanding inherent resilience in this regard, having a "**sense of community**" is a social cognitive variables that can be used to predict preparedness and resilience to a natural hazard[4]. **Feelings of belonging related to social justice, trust, participation, and empowerment within the system** can be measured. People with strong feelings of belonging to a place are shown to be more likely to convert intentions of preparedness into actual household preparations. Areas of **concentrated poverty** tend to have lower participation rates in institutional resources such as businesses, schools, social clubs, and other organizations. Furthermore, poor communities are plagued by **lower levels of trust and lowered expectations of reciprocal behavior**. Therefore, there is a diminished chance that neighborhoods will aid one another and limited social support is available in the face of a disaster or other crisis. Yet, not all impoverished communities lack strong social ties—others have found that the inner-city poor and other disenfranchised groups are as well networked as anyone else. However, they are less likely to have financial reserves in these networks to recover from a disaster. **A recent study examined earthquake recovery in two incidents in Japan and India with a focus on the strength of social networks in recovery**
neighborhoods in Kobe, Japan (affected by a 1995 earthquake) and Gujarat, I
quake) were studied. Victims were surveyed using the "Integrated
rement of Social Capital" developed by the United Nations. Based on the
unities with the highest levels of social capital (including external
yed the fastest recovery, despite lower income levels. The Kobe earthquak
of disaster management from an engineering issue to a social and technica

lation and social vulnerability, in particular among minorities, lower inco
ociated with delayed evacuation, greater incurred damage, fewer reso
building[6]. Furthermore, **because of these phenomena, disasters cause**
ding increased socioeconomic disparity as populations relocate. Soc
endent of physical space; however, networks are often organized or
ularly in times of need, ad hoc networks may form locally to mobilize
rks are associated with many benefits to individuals, households, and
ological, and social well-being, employment opportunities, **access t**
mation seeking, and utilization of social services, and community mo
aster resilience, social networks in urban communities have been sho
reducing vulnerability in preparing for and responding to a disaster, for fa
mitigation tactics such as evacuations from the bottom-up[7], and for im
disaster preparedness by increasing the perception of the availability of resou
support through social networks occur after a disaster (so-called new "sy
these support networks fall prey to pre-existing conflicts and tend to dissolve
underway. During a disaster, various types of social networks are utilized or fo
religious, political, economic, medical, educational, scientific, legal, risk
c), mass media, communications, transportation
construction, rebuilding, land use, and environ
rks may not have been part of original disaster planning
ed and incorporated into plans and preparations for fu
al to surviving and recovering from disasters and eit
ure resilience.

he areas of urban planning and sociology can be divided into two distinct
mined strategies for pre-disaster mitigation and those that focused on
f events. Land use planning and zoning were early tools employed by
achment in waterways in order to protect human property from flood damage

[6] Van Zandt et al., 2012
[7] Aguirre, 2006

Role of actors, institutions and infrastructure at the city level and their interactions

Outcome/output: Including social cognitive indicators to understand how communities actually operate and respond

Meso-level context of enabling environment: existing tools and zoning controls in neighborhoods

Output to:

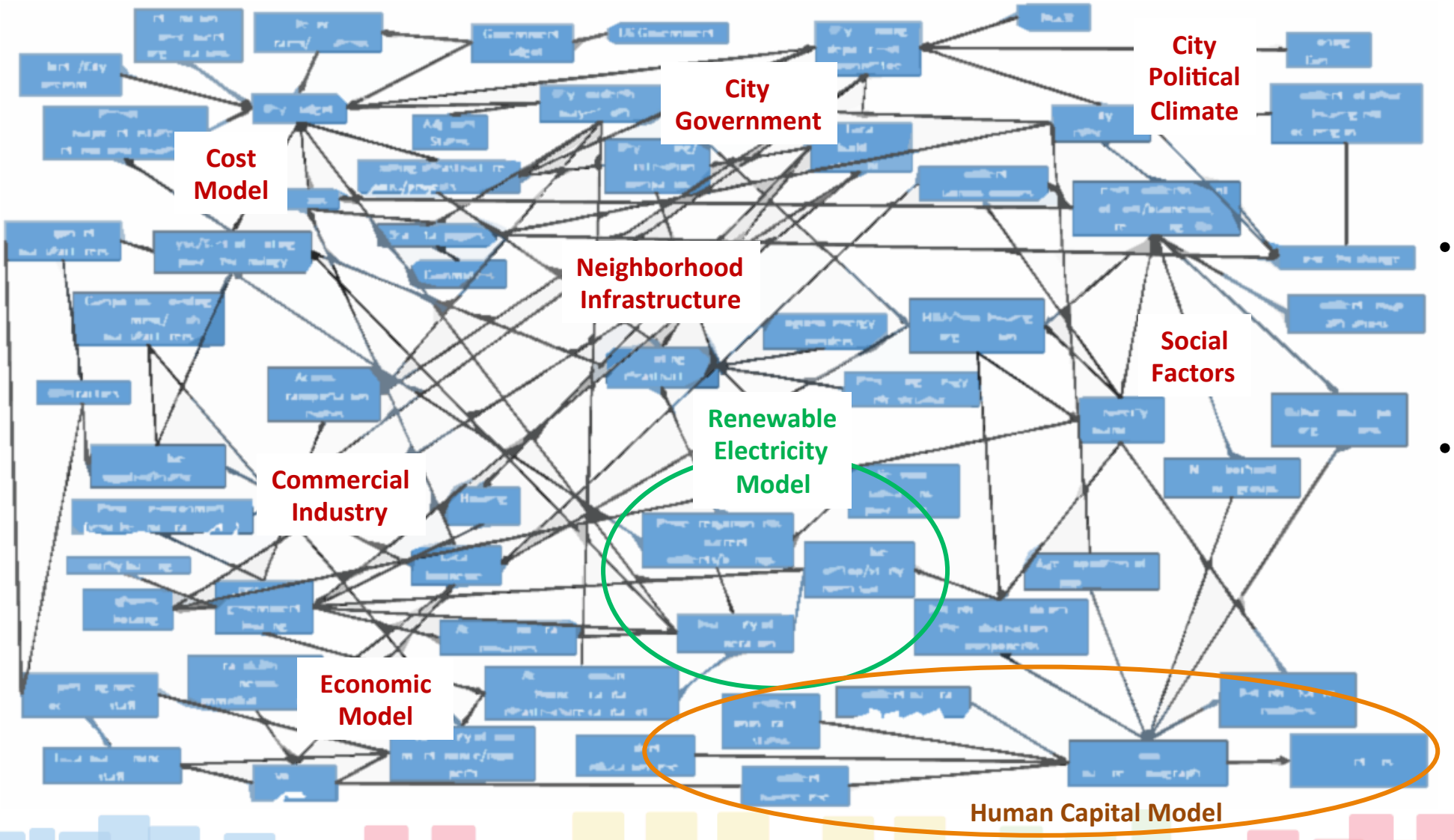
- **Conceptual Model**
- **Constructs & Relationships**
- **Contextual Search Tools**

Context Analysis Table

Could implementation of a microgrid in government subsidized housing increase urban resilience against natural and manmade events?

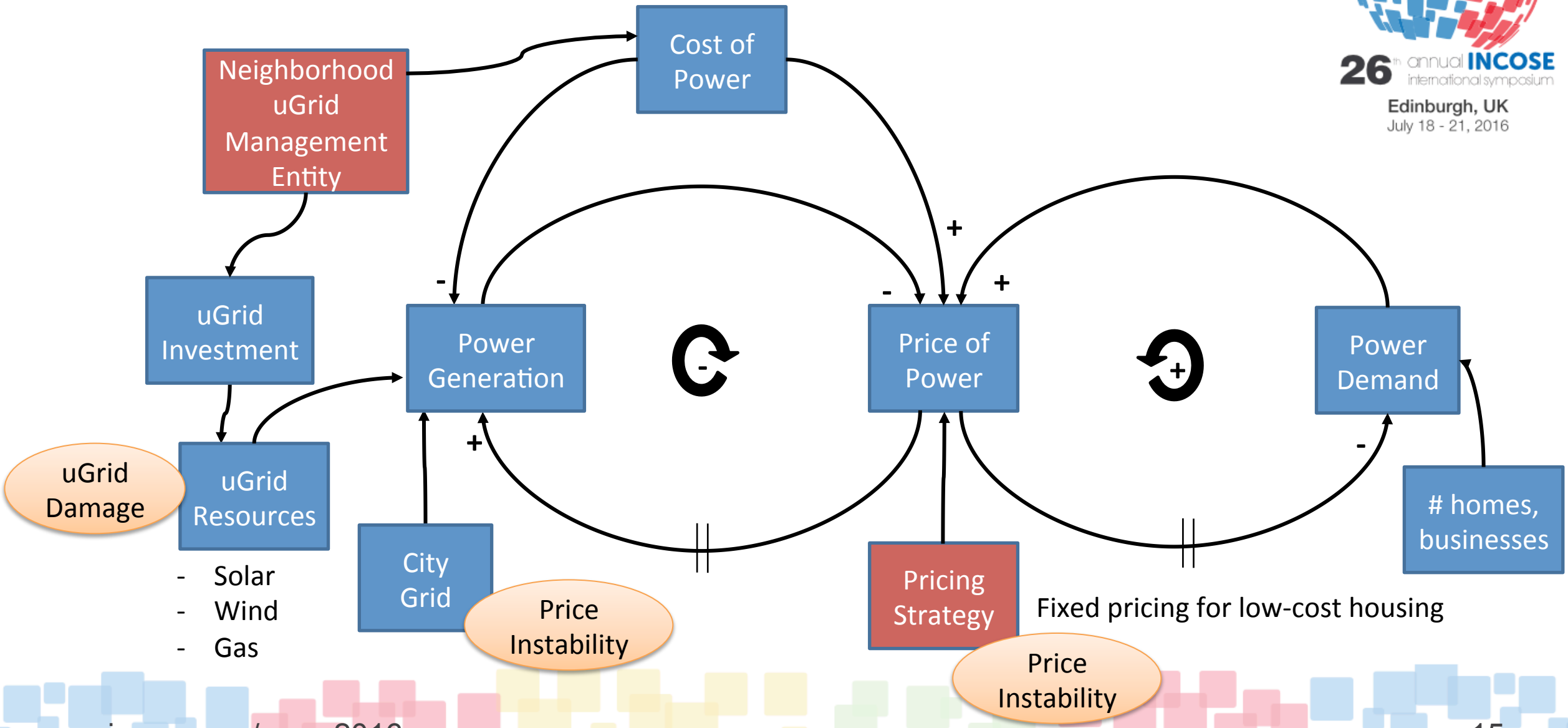
	Enabling Environment	Actors/Inputs	Interactions	Outputs/Outcomes
Macro (city)	• City budget • Existing Infrastructure • Type/Cost of existing power technology	• Available materials • Potential major investors • Construction companies	• Establish and enforce new zoning codes • Enable partnerships between organizations • Provide planning	• Provide platform for further city expansion • More flexible and reliable power grid • Power generation that inherently scales
Meso (neighbor-hood)	• Zoning controls • Existing Infrastructure or Projects in work • Access to Resources	• HOA/Local housing organization • Volunteers • Local/surrounding businesses	• Engineers to train local maintenance • Construction labor • Local project management	• Less expensive power • Integration of future technologies • Independence for building management
Micro (building/ person)	• Housing Size • Resident income level • Resident education level	• Current residents • Residents of Housing not Receiving Microgrid • Future residents	• Grow customer base • Utilize and Pay for Microgrid Outputs • Provide local maintenance	• Improve resident quality of life (QOL) • More reliable power • Greater self-sufficiency

Example Sociotechnical Systems Model



- Project: Urban Microgrids for Government-Assisted Housing
- Question: Can we optimize the human capital measures of a sustainable development project?

Policy Modeling – Economic Viability



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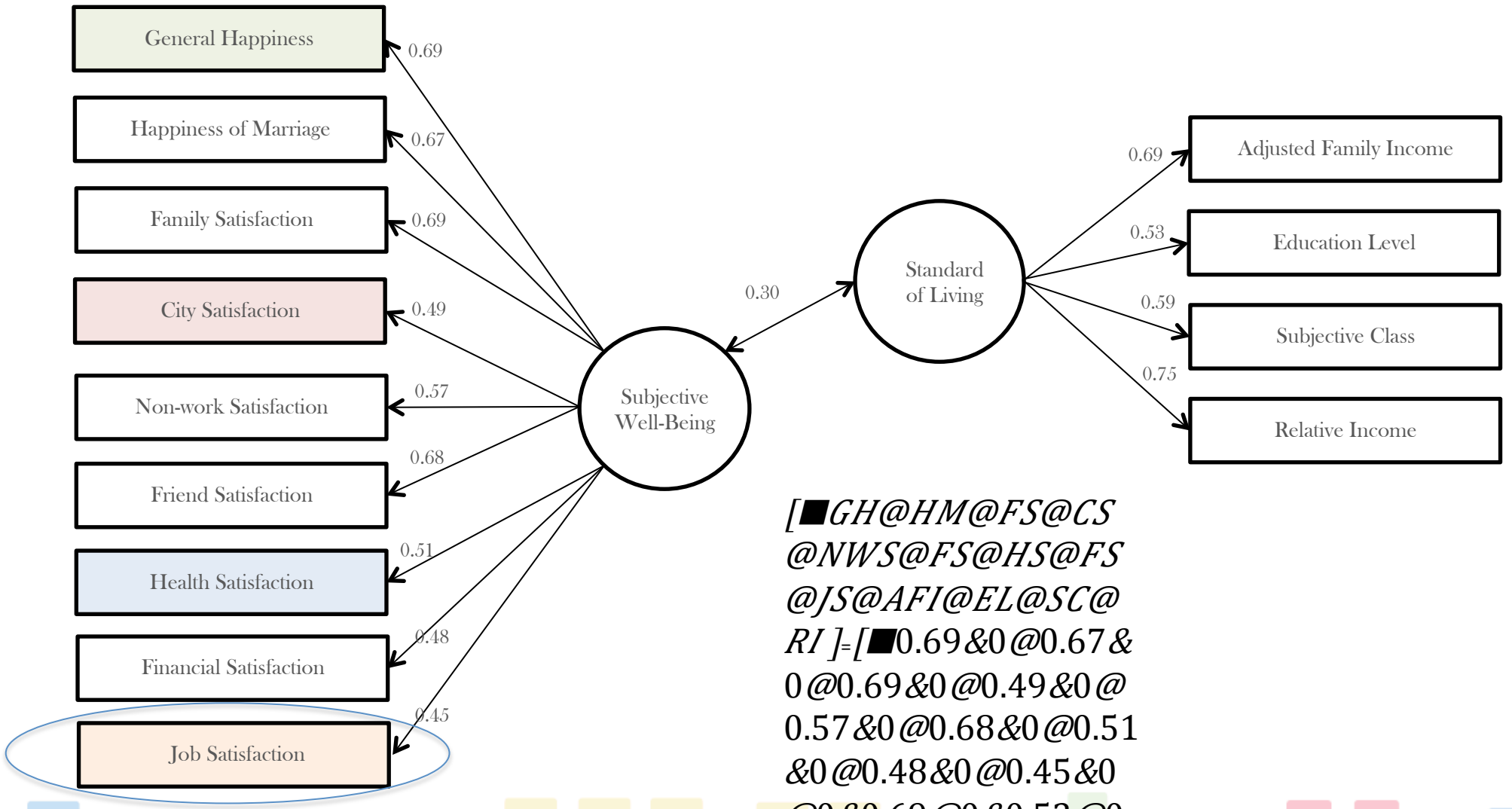
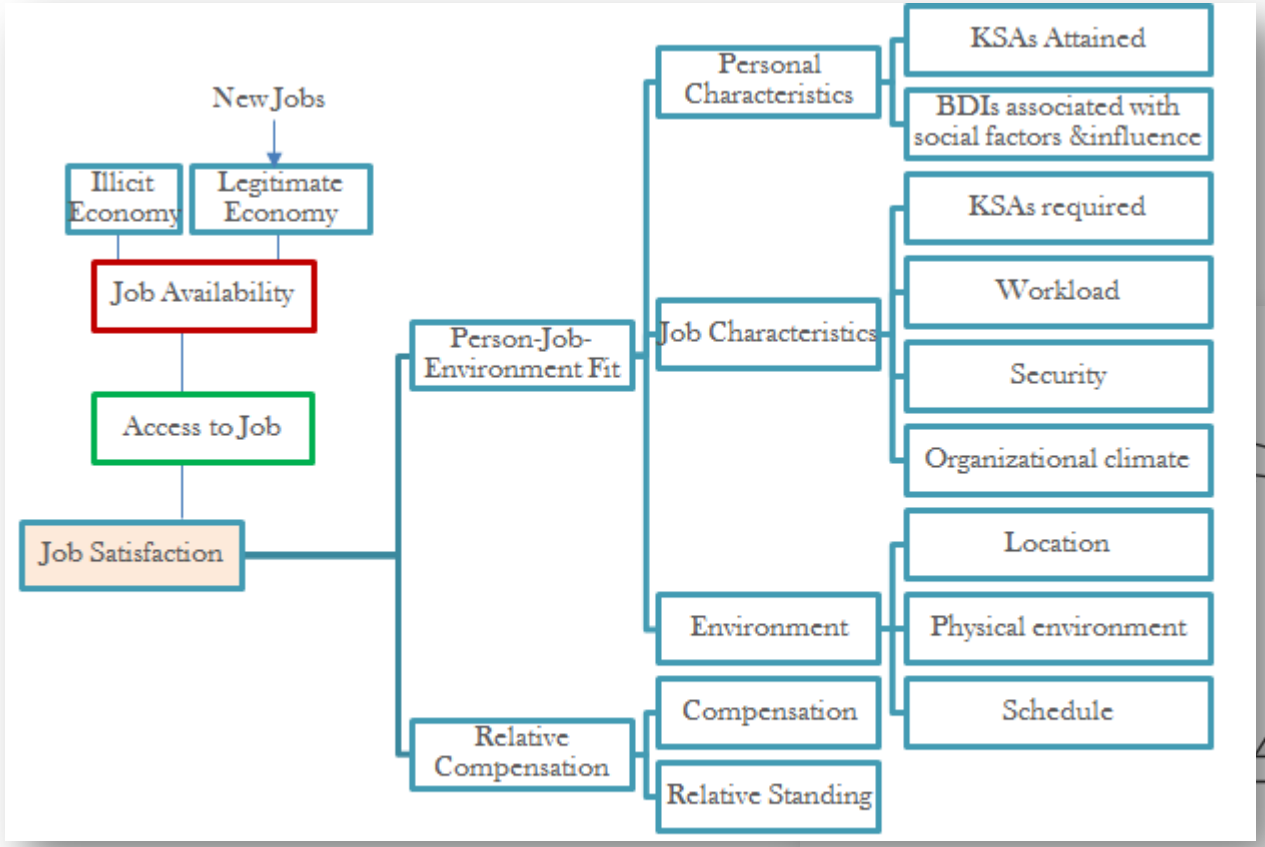
2-Factor Human Capital Structured Equation Model



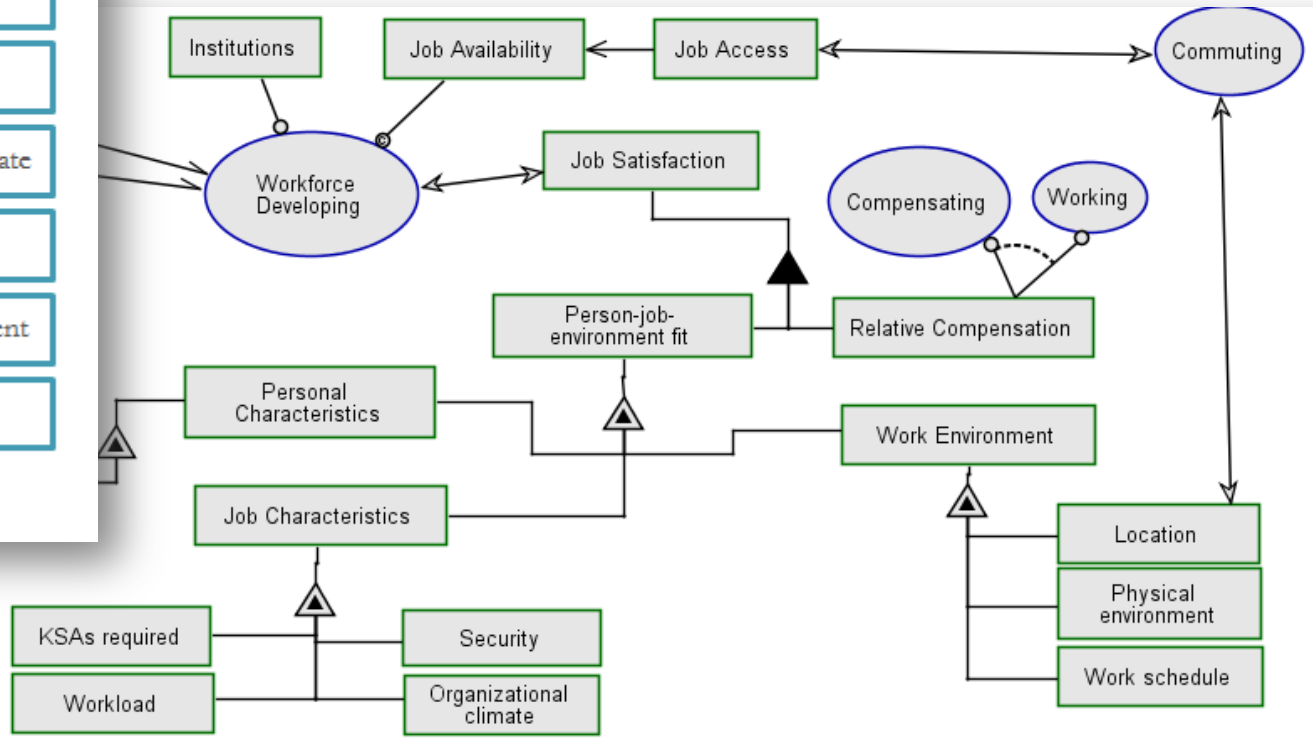
[■GH@HM@FS@CS @NWS@FS@HS@FS @JS@AFI@EL@SC@ RI]=[■0.69&0@0.67& 0@0.69&0@0.49&0@ 0.57&0@0.68&0@0.51 &0@0.48&0@0.45&0 @0&0.69@0&0.53@0 &0.59@0&0.75] [■SWB@SOL]+[■

Job Satisfaction Models

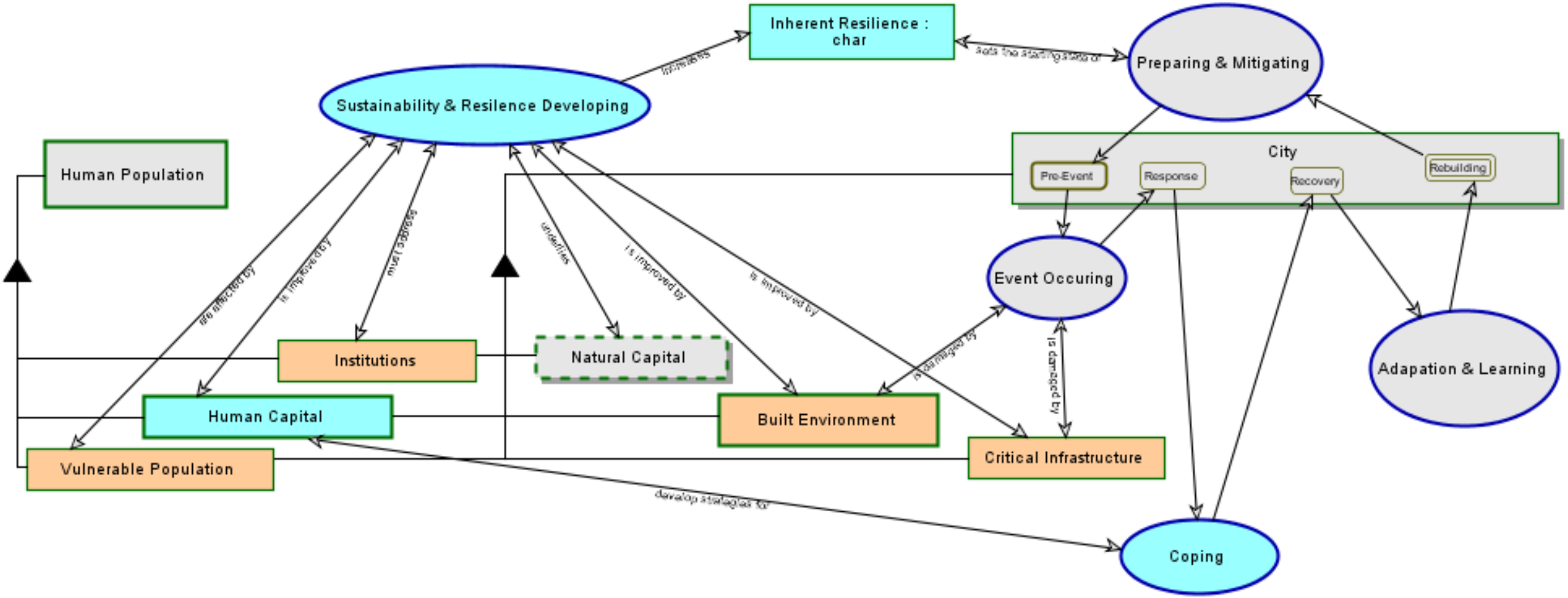


Factor Analysis

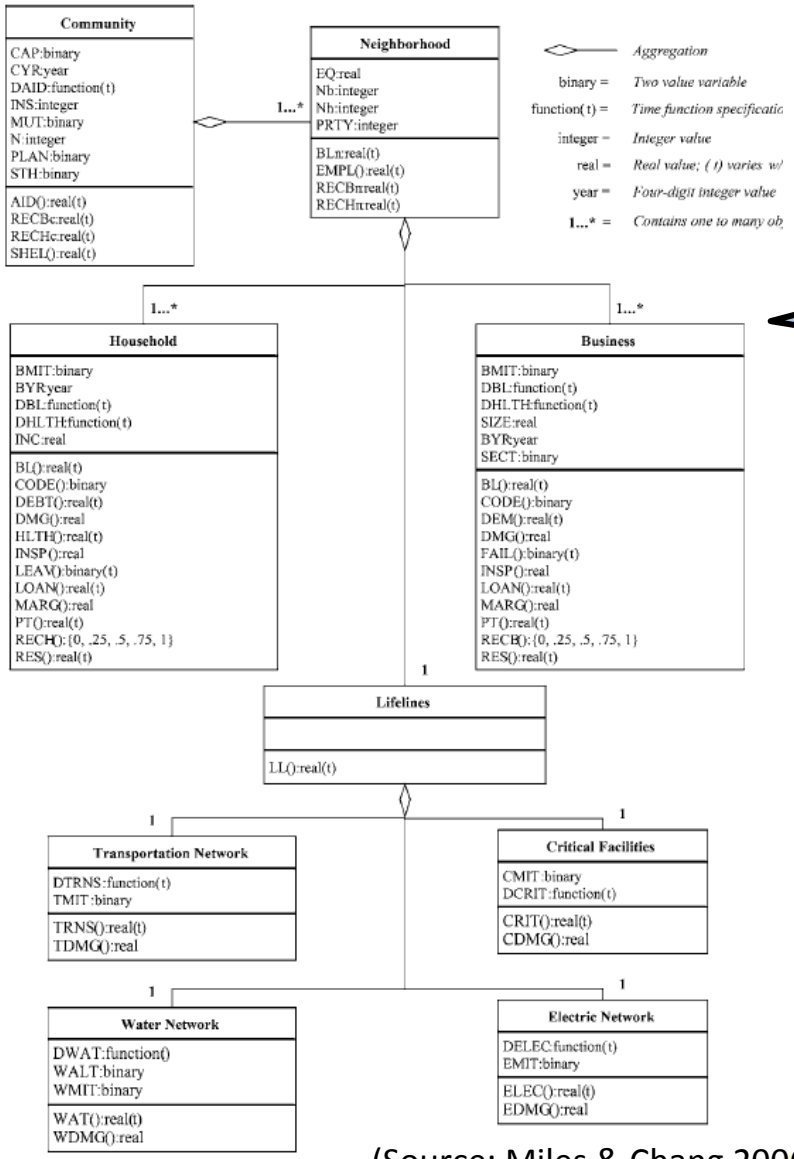
Object-Process Models



Broader Object Process Model of Community Resilience



Entity-Relationship Models of Community Resilience



(Source: Miles & Chang 2006)

Initial UML Model of Built Infrastructure

Initial Qualitative Model of Social Resilience

Atlanta's Neighborhood Quality of Life & Health Project, http://www.cgis.gatech.edu/NQOLH/

Agenda

- Community Resilience Architecture
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- ➢ Conclusions & Continuing Study

Conclusions

- Novel approach to combine socio-environmental and psychological factors of community resilience
- Requires methods for qualitative and quantitative analysis and visualization into a single SE framework
- Developed conceptual framework and tools
- Developing dynamic and computational models
- Long-term study on SE frameworks for experimentation
- Relevant testbed environment in Atlanta, GA

Collaborative Systems Engineering Frameworks

To support the design of systems of systems through a resilient implementation and analysis process.

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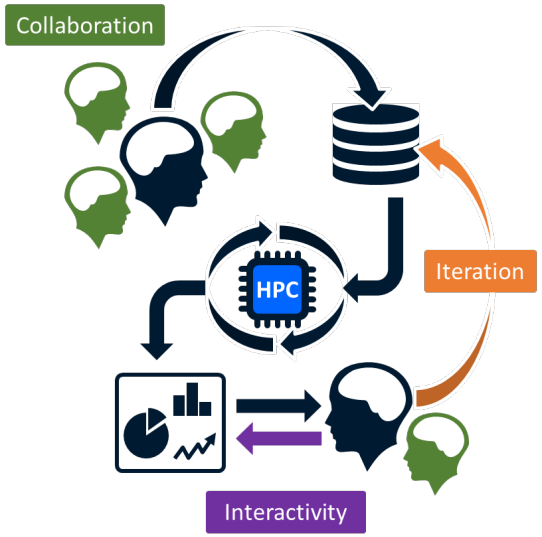
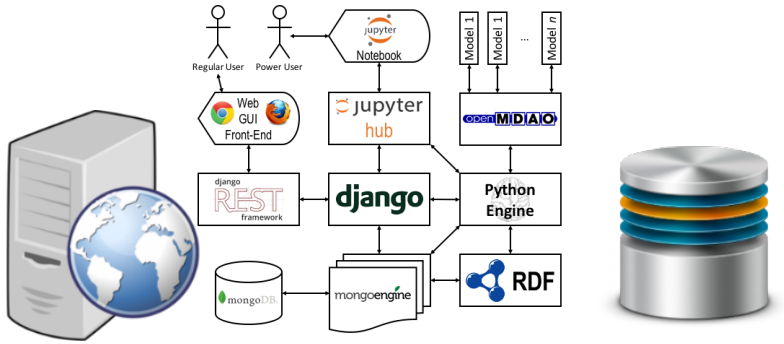
Collaborative SE



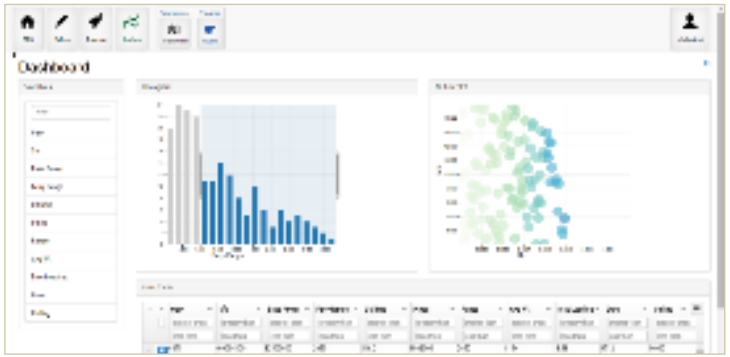
End-to-End Capability

Scalable Framework



Server or Stand-Alone Execution

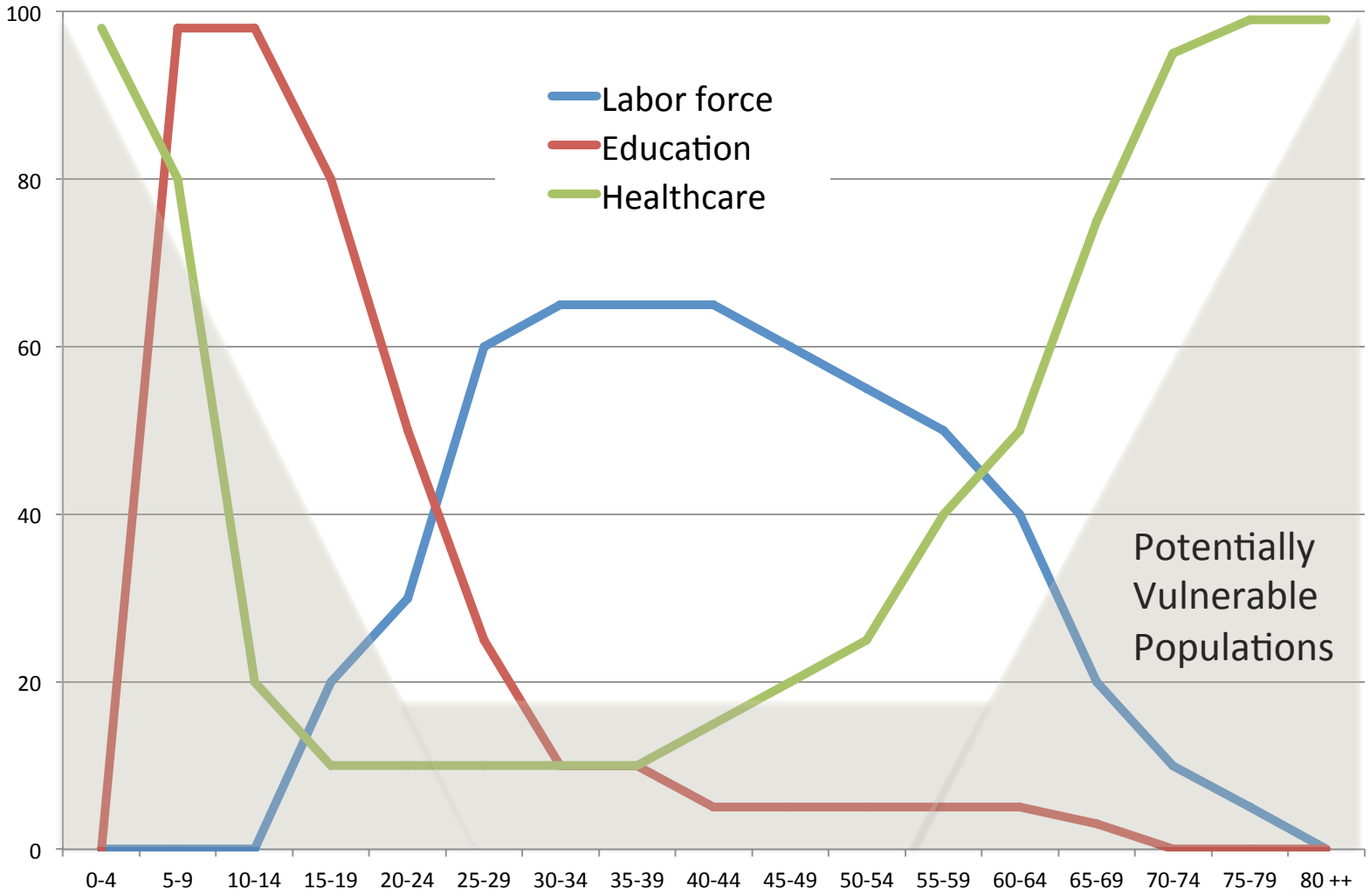
Dynamic, Customizable, and Visually Interactive



Method and Stakeholder Fluid

Integrate Requirements, Design, and Knowledge Generation

Human Capital & Community Vulnerability

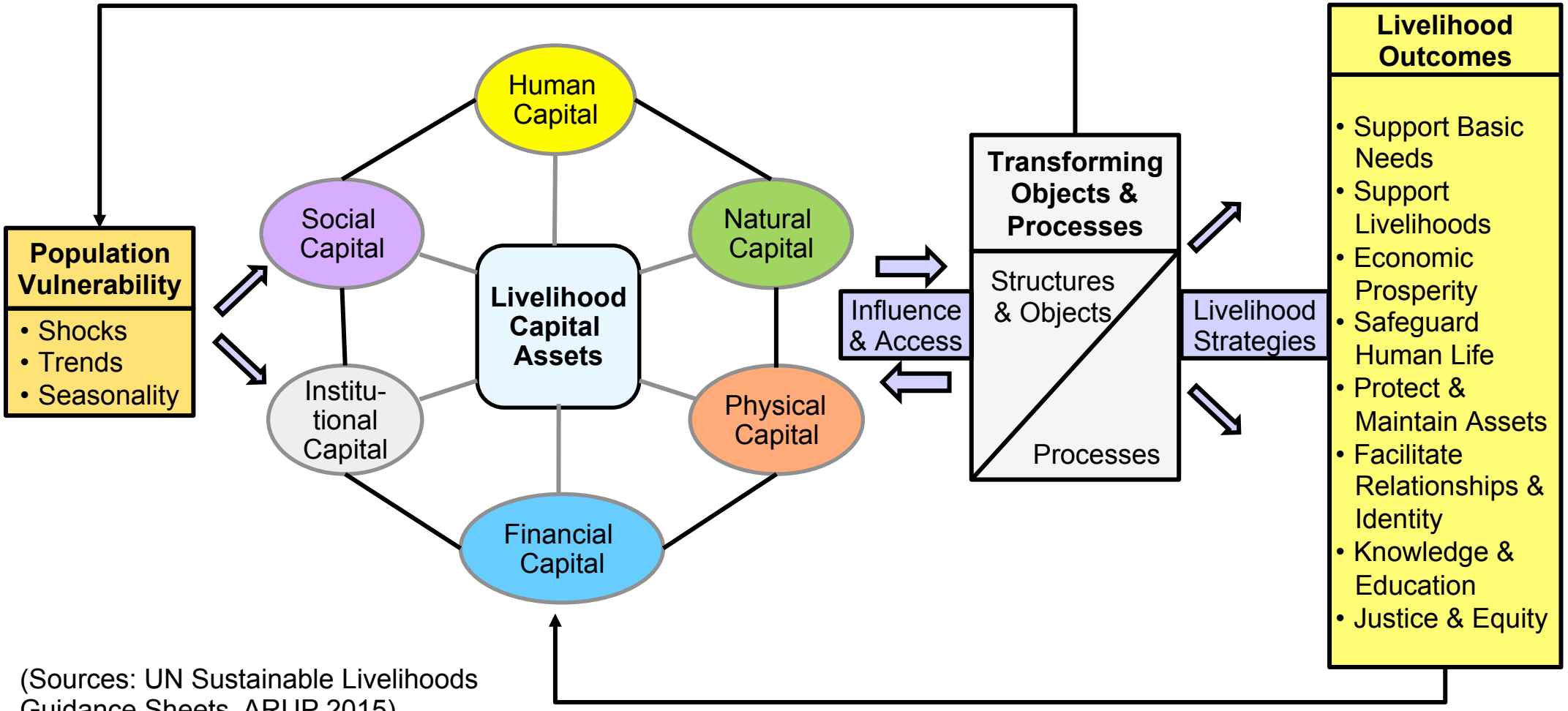


Notional Model of Human Capital impact on Health, Education, and Employment systems

Primary social sustainability and resilience factors are a function of vulnerabilities and access to capitals

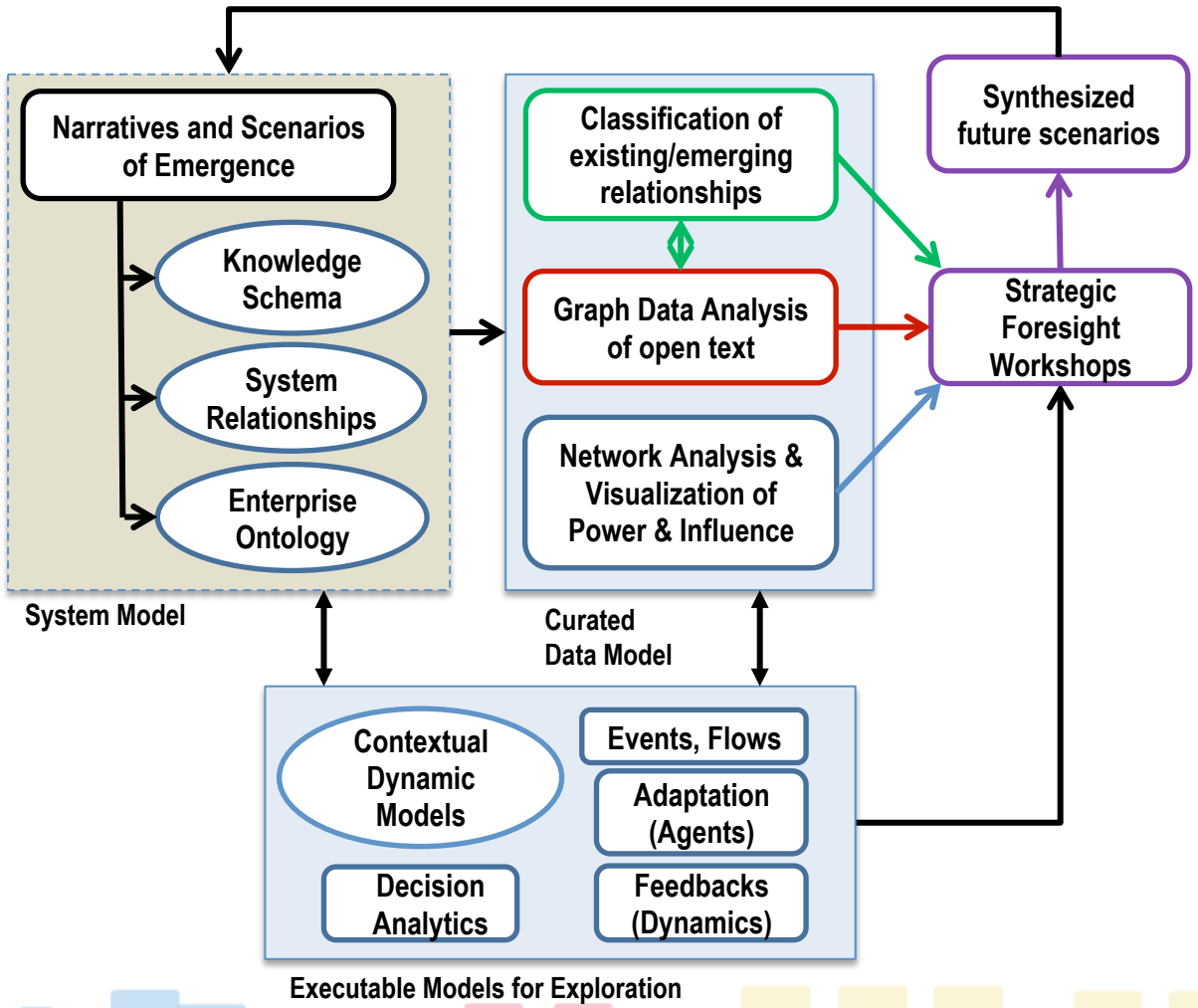
(Sources: Cutter 2008, Folds 2015)

Conceptual Functional Model of Community Sustainability & Resilience



(Sources: UN Sustainable Livelihoods Guidance Sheets, ARUP 2015)

Emerging Knowledge Management Environment



- **Descriptive System Model** maps emerging system relationships using narratives of emergence
- **Data model** curates causal relationships, text graphs, and entity-based knowledge graphs for long-term experimentation
- **Data analytics** and **executable modeling** environments are combined for long and short term decision analysis
- **Foresight Workshops** convene virtual think tanks for scenario generation and gaming