

# Modeling and Reasoning with Changing Intentions: An Experiment

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UNIVERSITY OF  
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# Overview

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## Problem:

We investigate the effectiveness and usability of

- Evolving Intentions,
- Simulation over Evolving Intentions, and
- GrowingLeaf

## Practitioners:

- Improves decision making in early-RE
- Consider short-term and long-term impacts of alternatives

# Motivating Scenario

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A City is evaluating waste management options for its Citizens.

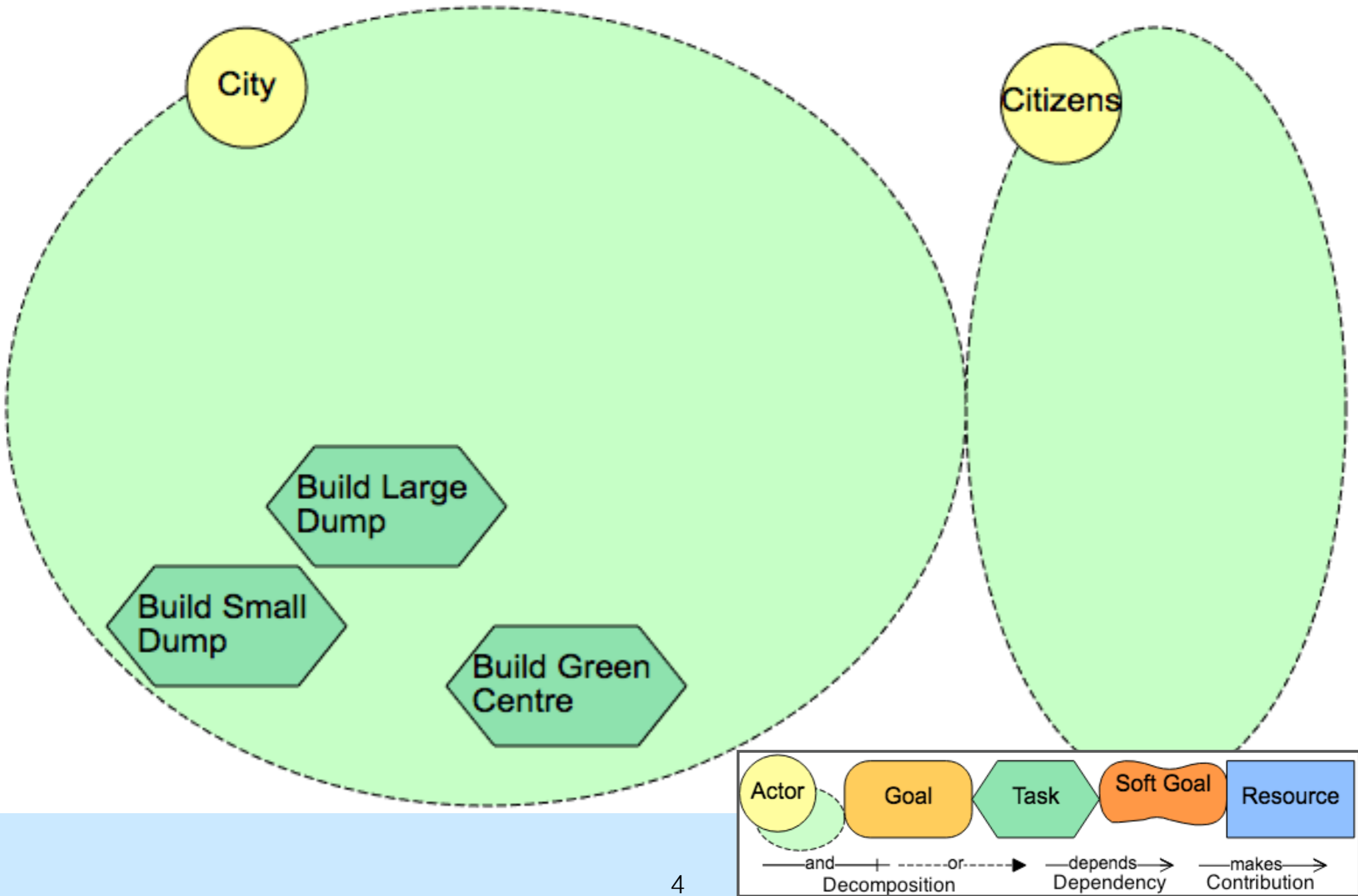
Options: Build Green Centre  
Build Landfill / Dump (large, small)



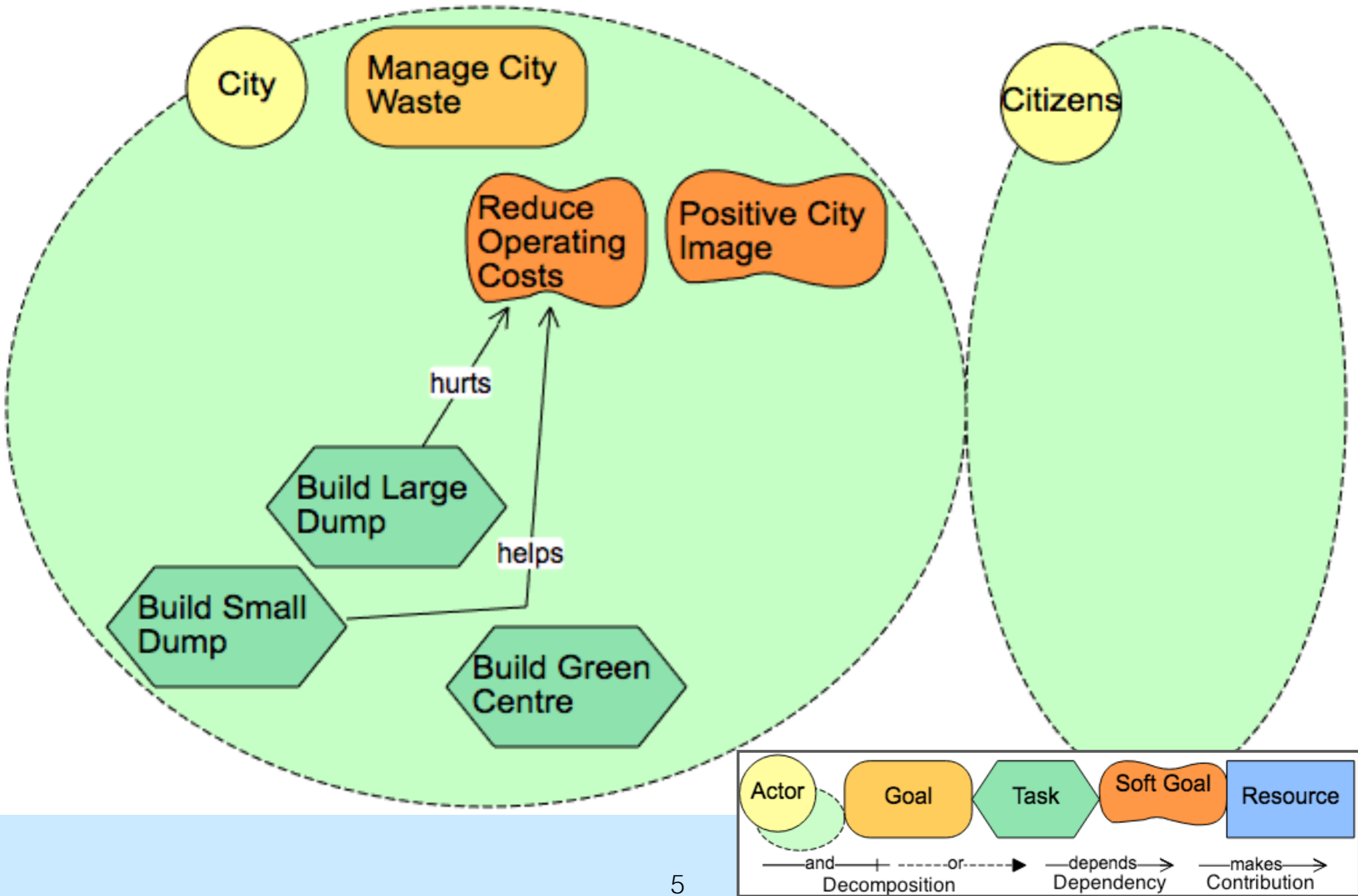
Choose the best alternative(s) using goal modeling.



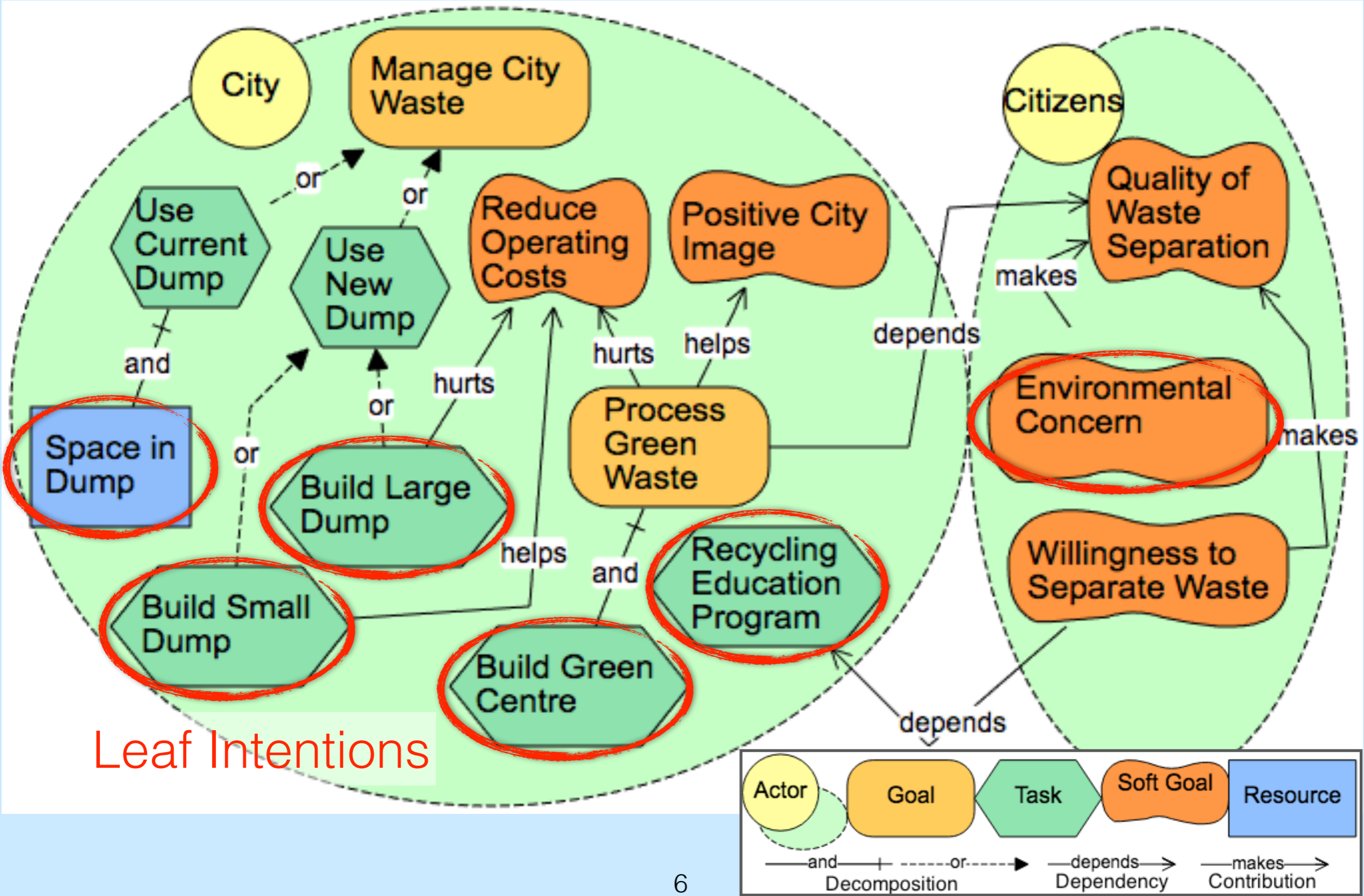
# Waste Management Example



# Waste Management Example



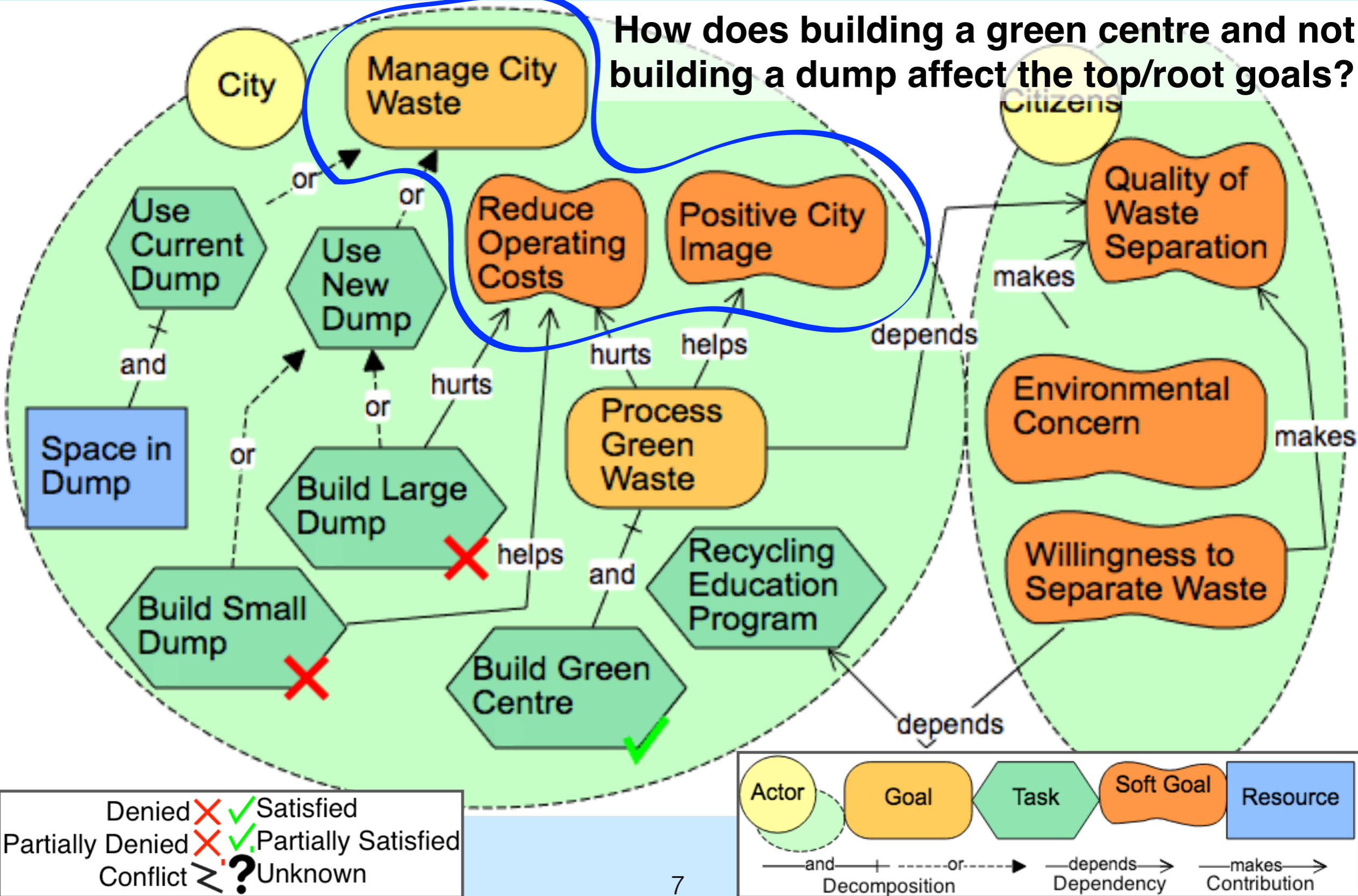
# Waste Management Example



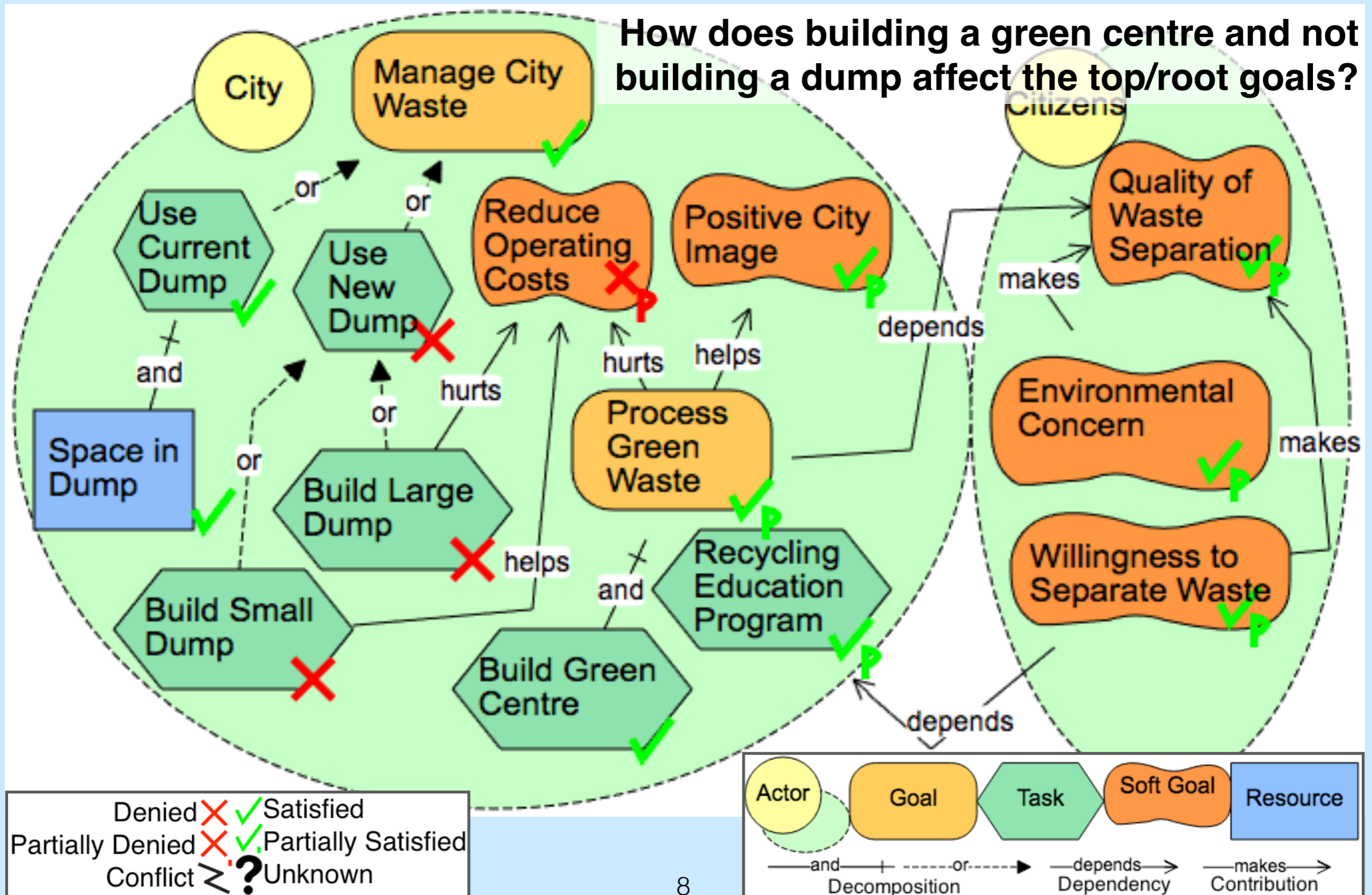
# Waste Management Example



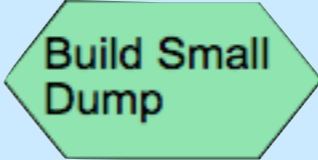
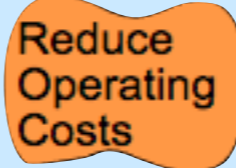
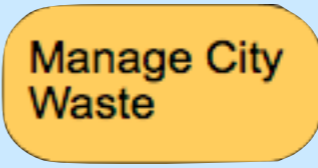
# Waste Management Example

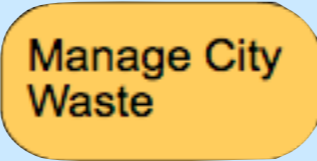
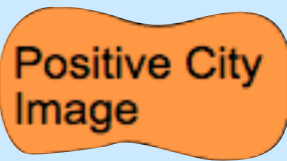
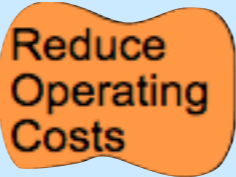


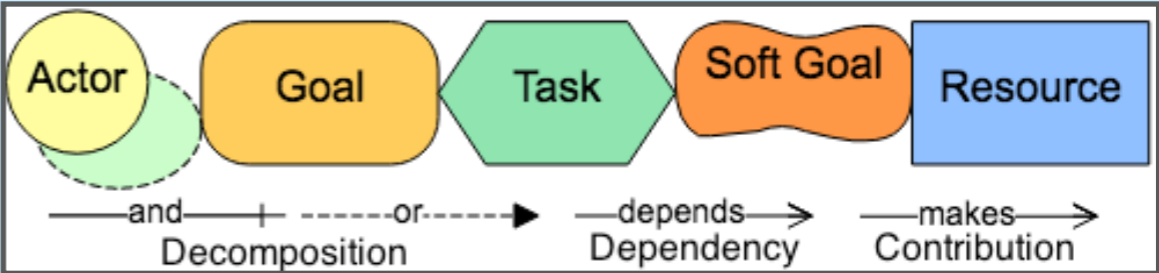
# Waste Management Example



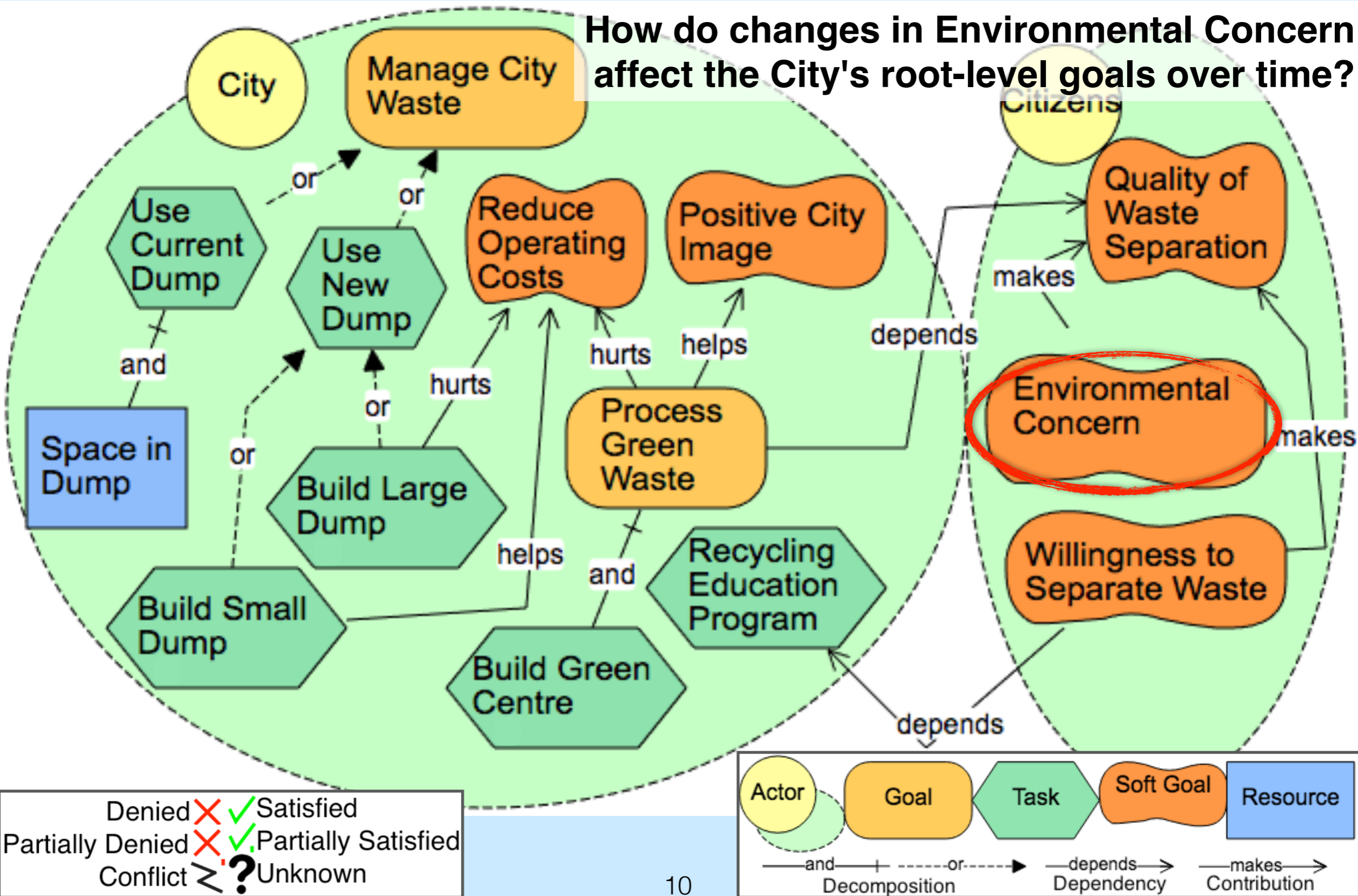
# Waste Management Example

Question: How does satisfying  and not satisfying (deny)  &  affect the top/root goals?   

Answer: It satisfies  partially satisfies  but partially denies 



# Waste Management Example

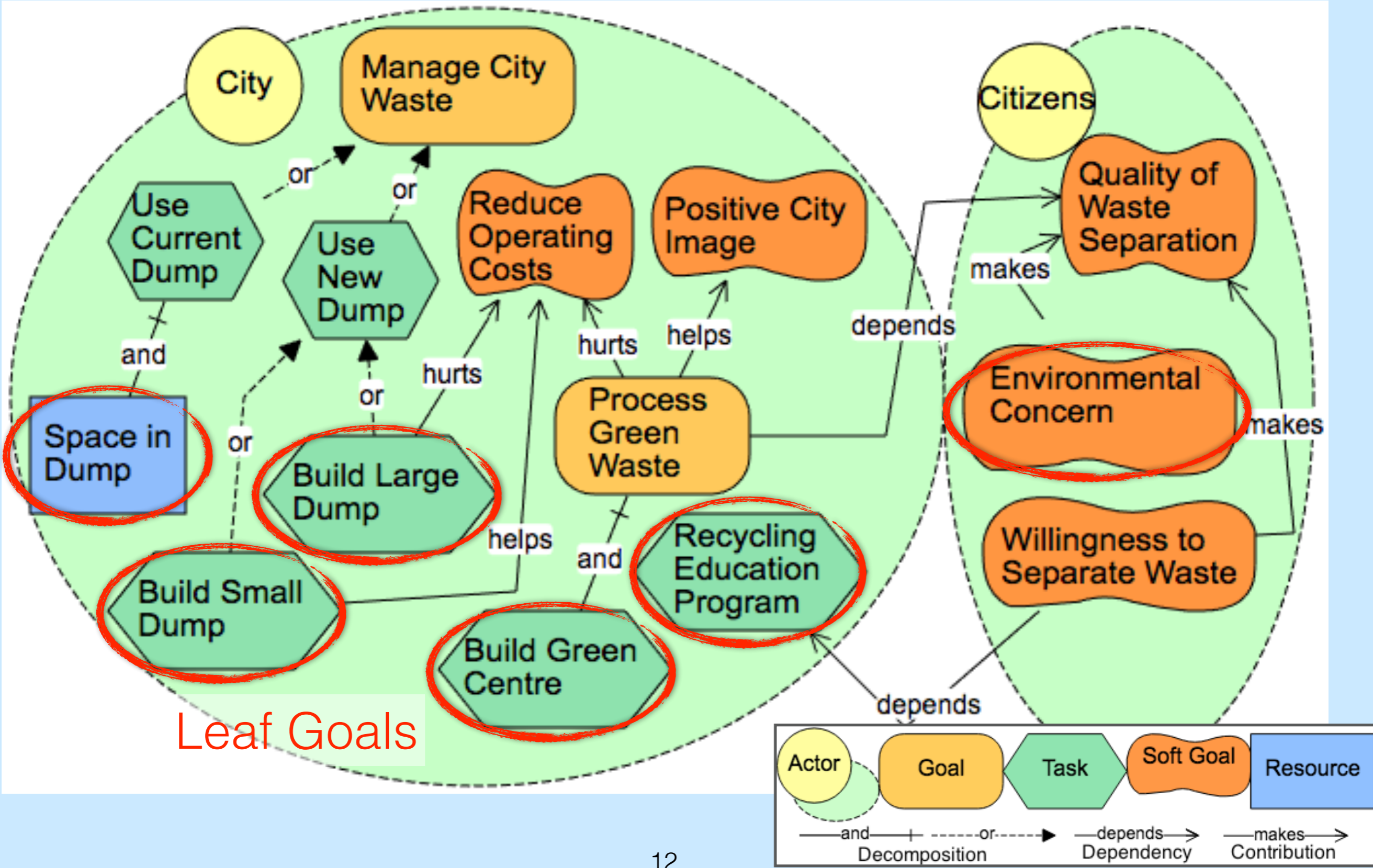


# Previous Work

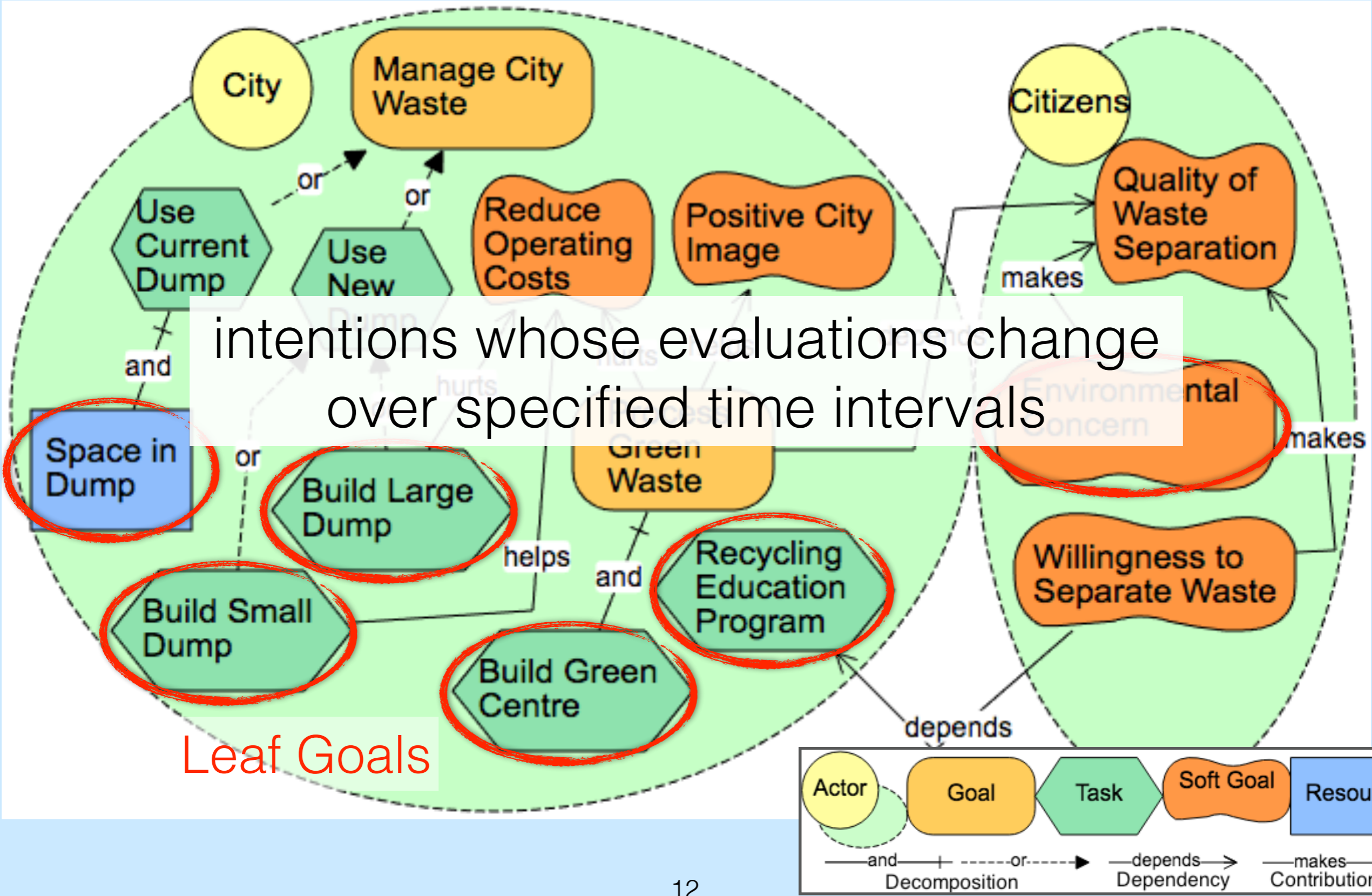
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- “Looking into the Crystal Ball:  
Requirements Evolution over Time.” [RE’16]
- *Allow* goal model *intentions to change* over time  
[Evolving Intentions (EIs)]
  - *Understand the impacts* of dynamically changing  
intentions *on decision making*  
[Simulation over Evolving Intentions (EI-Sim)]
  - *Tooling* for modeling and analyzing intentions that  
change over time. [GrowingLeaf]

# Evolving Intentions



# Evolving Intentions



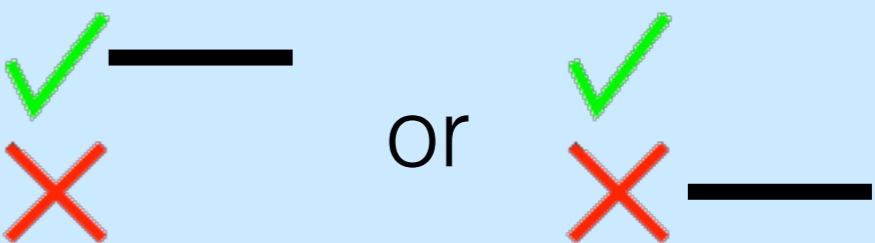
# Evolving Intentions

## Elementary Functions

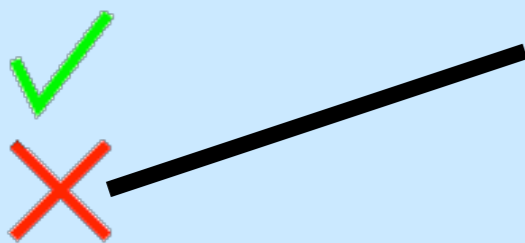
Stochastic (R):



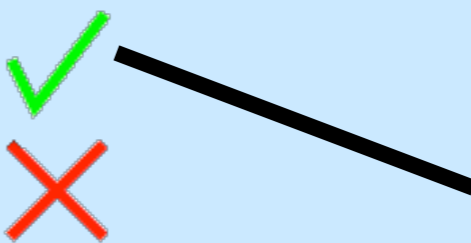
Constant (C):



Increase (I):



Decrease (D):

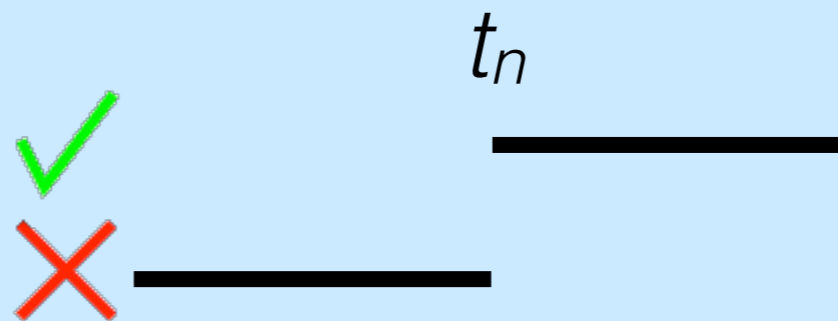


# Evolving Intentions

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## Denied-Satisfied (DS)

Patterns:



Examples:

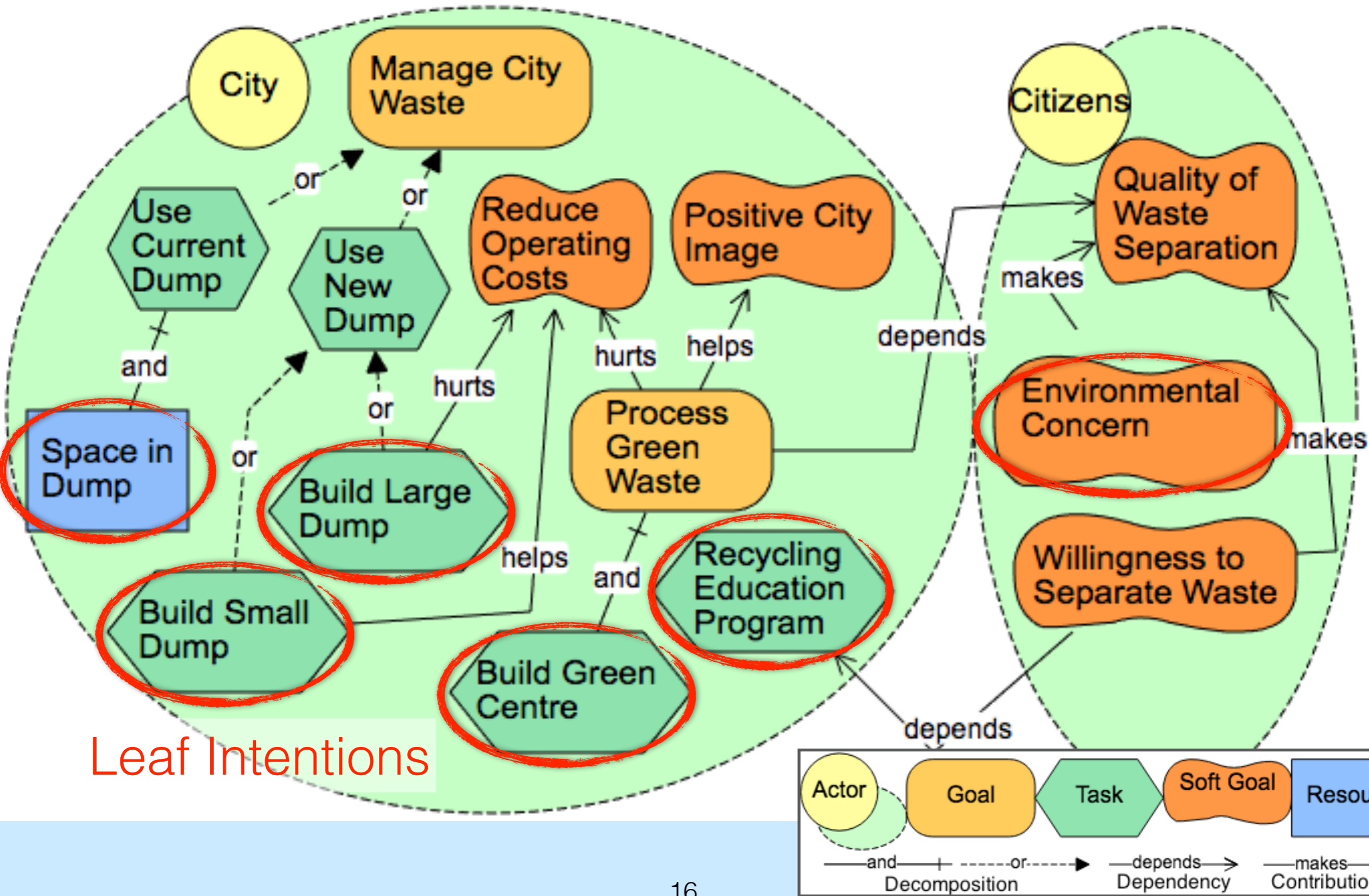


# Evolving Intentions

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Satisfied-Denied (SD)	the satisfaction evaluation remains <i>Satisfied</i> until $t_i$ and then remains <i>Denied</i>
Denied-Satisfied (DS)	the satisfaction evaluation remains <i>Denied</i> until $t_i$ and then remains <i>Satisfied</i>
Stochastic-Constant (RC)	changes in satisfaction evaluation are stochastic or random until $t_i$ and then remains constant at <i>constantValue</i>
Constant-Stochastic (CR)	the satisfaction evaluation remains constant at <i>constantValue</i> until $t_i$ and then changes in evaluation are stochastic or random
Monotonic Positive (MP)	changes in satisfaction evaluation become “more true” to a <i>maxValue</i> at $t_i$ and then remains constant at <i>constantValue</i>
Monotonic Negative (MN)	changes in satisfaction evaluation become “less true” to a <i>maxValue</i> at $t_i$ and then remains constant at <i>constantValue</i>

# Simulation over Evolving Intentions

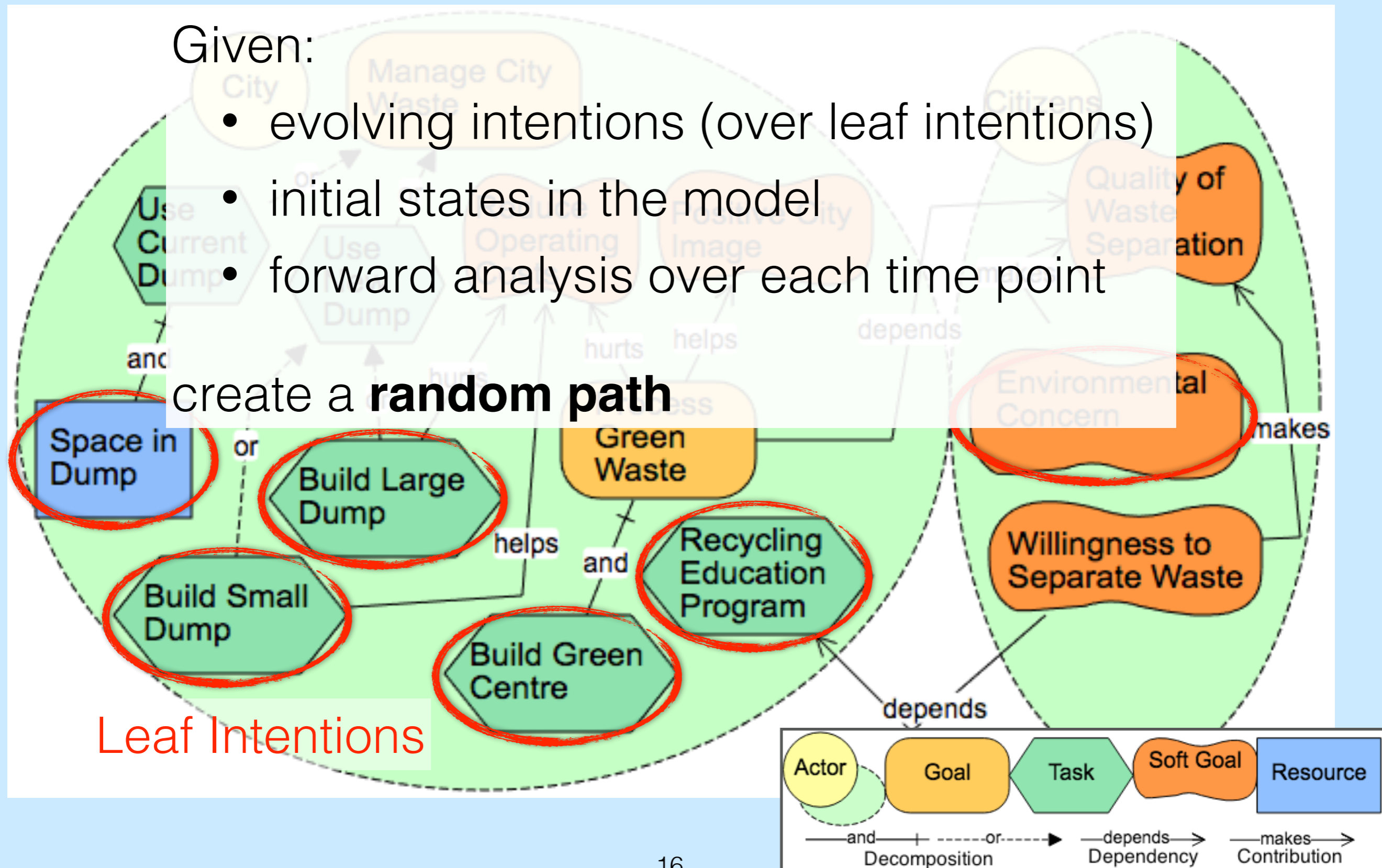


# Simulation over Evolving Intentions

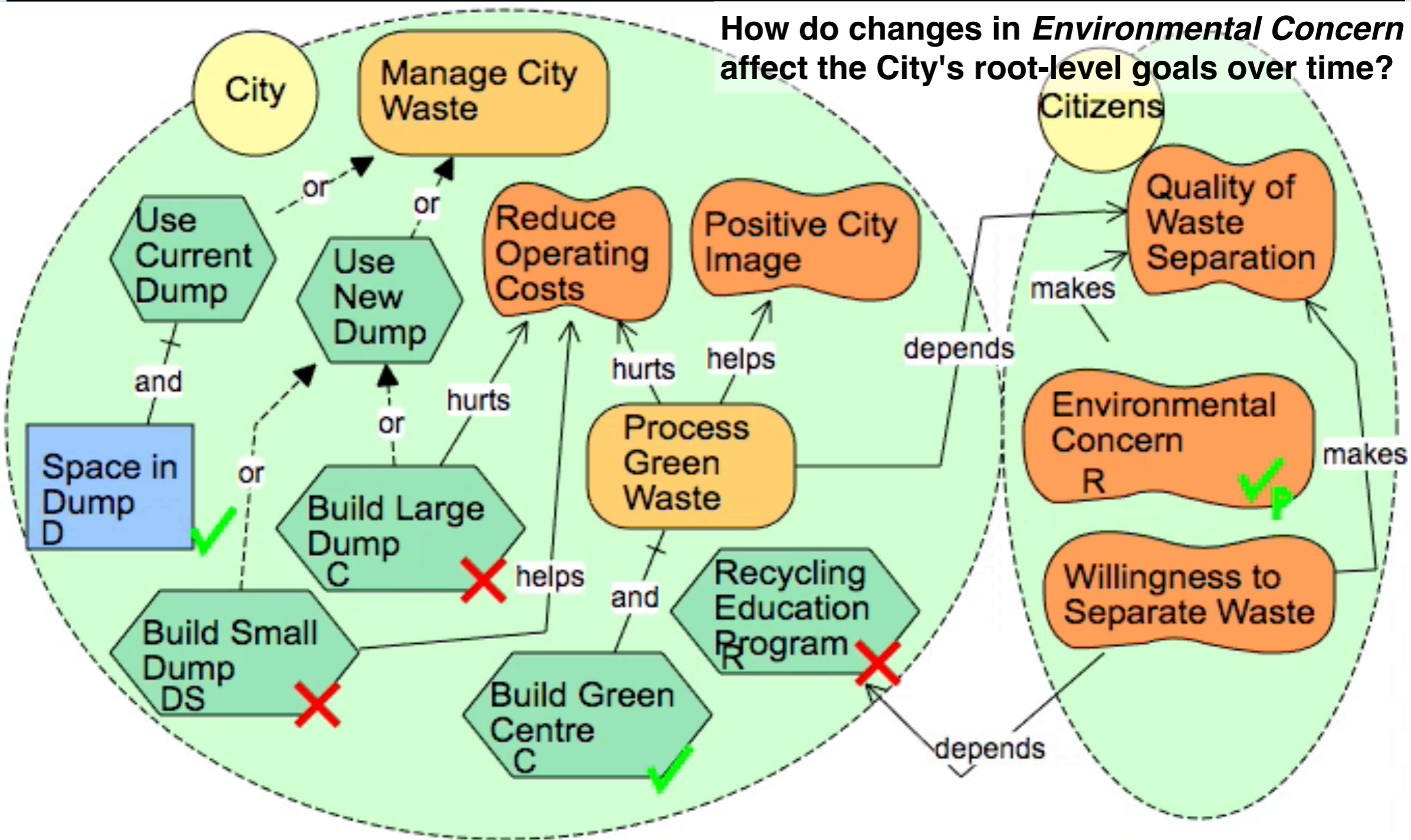
Given:

- evolving intentions (over leaf intentions)
- initial states in the model
- forward analysis over each time point

create a **random path**



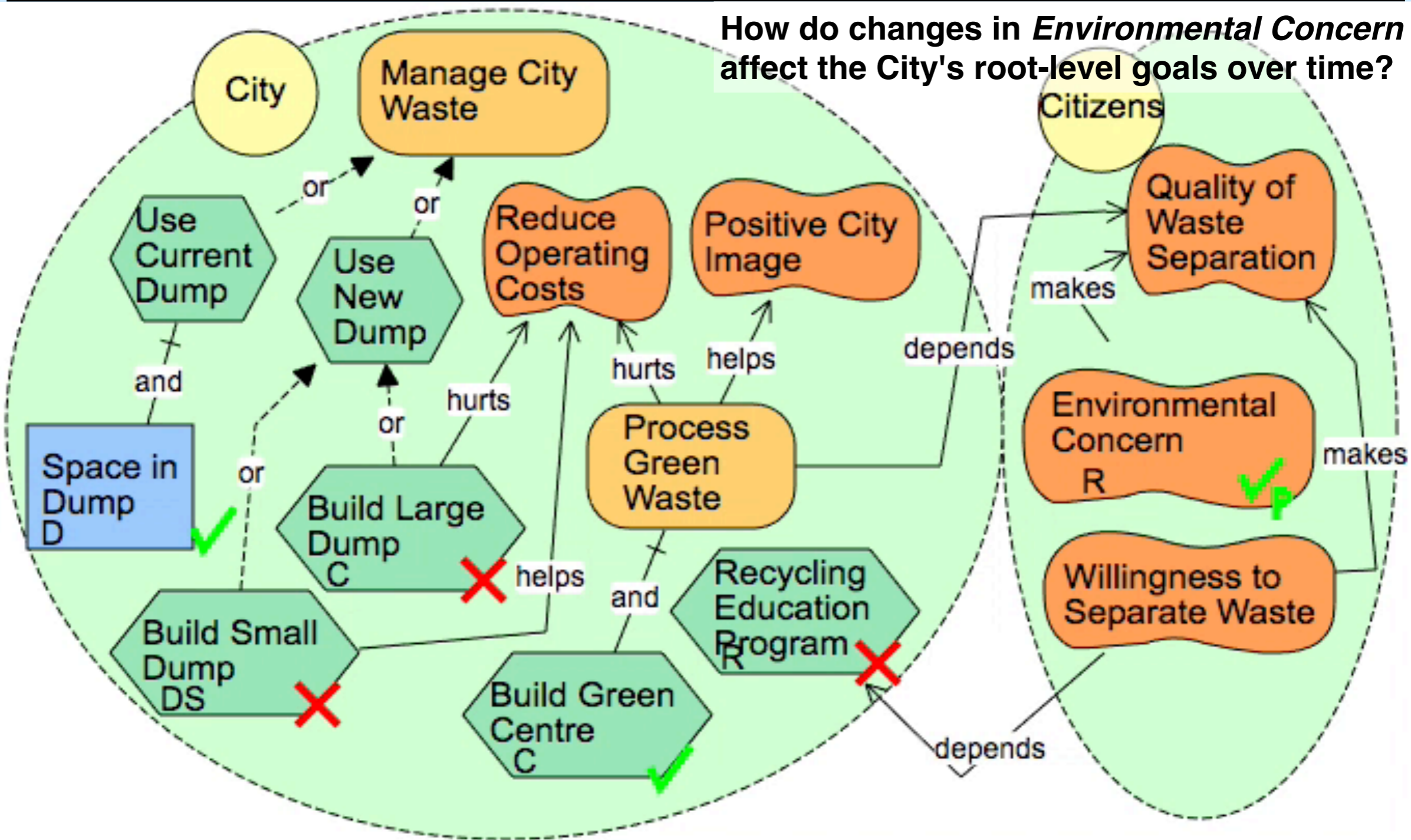
# Simulation over Evolving Intentions



R:Stochastic, C:Constant,  
D: Decrease, DS:Denied-Satisfied



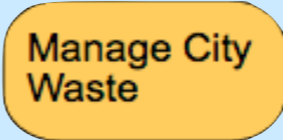
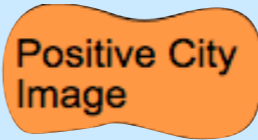
Denied X ✓ Satisfied  
Partially Denied X ✓ Partially Satisfied  
Conflict ≥ ? Unknown

# Simulation over Evolving Intentions

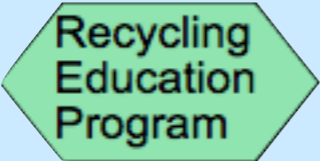
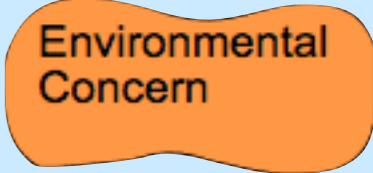


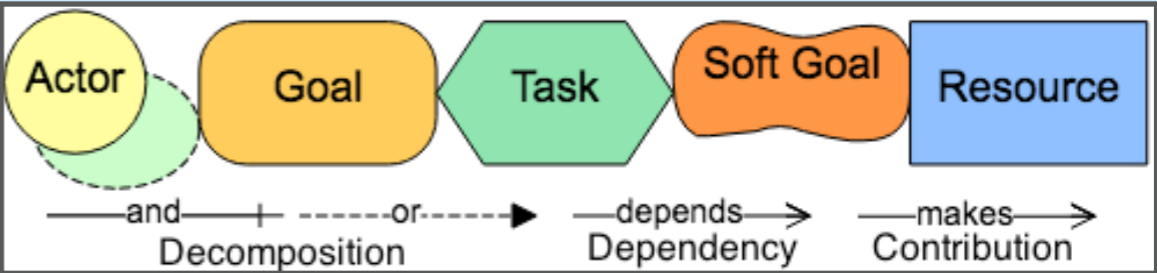
R:Stochastic, C:Constant,  
D: Decrease, DS:Denied-Satisfied

# Waste Management Example

Question: How do changes in  affect the city's root-level goals    over time?

Answer: Affects  

Satisfying  mitigates the effect of denied 



# GrowingLeaf

Goal

Task

Soft Goal

Resource

Actor

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JointJS: an HTML 5 diagramming  
component.  
<http://jointjs.com>

UndoRedoClearSaveLoadZoom InZoom OutOpen as SVGExport .leafFont SizeHelpModel ConstraintsAnalysis

Modelling Relationships

Node name:  
Build Green

Initial Satisfaction Value:  
Satisfied

Function Type:  
Constant

S

PS

R/S

PD

D

0

Infinity

<http://www.cs.toronto.edu/~amgrubb/growing-leaf>

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# Research Questions

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- (RQ1) How do Evolving Intentions (EIs) affect modelers' ability to capture model elements that change over time?  
*Control: Stochastically Evolving Intentions (SEIs)*
- (RQ2) How does Simulation over Evolving Intentions (EI-Sim) affect modelers' understanding and ability to reason about a goal model with time?  
*Control: Repeated Forward Analysis (Rep-FA),  
Simulation over Stochastically Evolving Intentions (SEI-Sim)*
- (RQ3) How do modelers evaluate GrowingLeaf after completing modeling and analysis tasks?

# Research Questions

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- (RQ0) Do modelers perform similarly on basic cognition tests, given a consistent training protocol?
- (RQ1) How do Evolving Intentions (EIs) affect modelers' ability to capture model elements that change over time?  
*Control: Stochastically Evolving Intentions (SEIs)*
- (RQ2) How does Simulation over Evolving Intentions (EI-Sim) affect modelers' understanding and ability to reason about a goal model with time?  
*Control: Repeated Forward Analysis (Rep-FA),  
Simulation over Stochastically Evolving Intentions (SEI-Sim)*
- (RQ3) How do modelers evaluate GrowingLeaf after completing modeling and analysis tasks?

# Outline

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- Motivating Example & Background
  - Evolving Intentions (EIs)
  - Simulation over Evolving Intentions (EI-Sim)
  - Tooling: GrowingLeaf
- **Study Design**
- Results
- Implication, Threat to Validity, & Reflections

# Tools & Videos

## Tools

Name	Rationale
GrowingLeaf-EI-Sim (Tool-EI)	Learning of EIs and EI-Sim
GrowingLeaf-SEI-Sim (Tool-SEI)	Control for SEI-Sim, prevents learning effect of EIs
GrowingLeaf-Forward Analysis (Tool-FA)	Intro version without EIs or SEIs, prevents learning effect of EIs or SEIs

Legend	
EI	Evolving Intentions
SEI	Stochastically Evolving Intentions
EI-Sim	Simulation over Evolving Intentions
SEI-Sim	Simulation over Stochastically Evolving Intentions
Rep-FA	Repeated Forward Analysis

# Tools & Videos

Legend	
EI	Evolving Intentions
SEI	Stochastically Evolving Intentions
EI-Sim	Simulation over Evolving Intentions
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Tools	Name	Rationale
	GrowingLeaf-EI-Sim (Tool-EI)	Learning of EIs and EI-Sim
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# Tools & Videos

Videos

Name		Description
RQ0	Video 0A	Reviewed goal modeling concepts/notations & introduced Tool-FA.
	Video 0B	Introduced forward analysis with Tool-FA.
RQ1	Video IEI	Introduced EIs.
	Video ISEI	Introduced SEIs.
RQ2	Video IIEI	Introduced EI-Sim with Tool-EI.
	Video IISEI	Introduced SEI-Sim with Tool-SEI.
	Video IIAFA	Introduced Rep-FA with Tool-FA.

Legend	
EI	Evolving Intentions
SEI	Stochastically Evolving Intentions
EI-Sim	Simulation over Evolving Intentions
SEI-Sim	Simulation over Stochastically Evolving Intentions
Rep-FA	Repeated Forward Analysis

Tools

Name	Rationale
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# Study Protocol

Recorded  
Answers &  
Completion  
Times

Legend: section topic, video watched, tool used

	Subject Groups			
	Group A (n = 5)	Group B (n = 5)	Group CA (n = 3)	Group CB (n = 2)
RQ0	iStar & GrowingLeaf, Video 0A, Tool-FA Forward Analysis, Video 0B, Tool-FA			
RQ1	EIs, Video IEI, Tool-EI	SEIs, Video ISEI, Tool-SEI		
RQ2	EI-Sim, Video IIEI, Tool-EI	SEI-Sim, Video IISEI, Tool-SEI	Rep-FA, Video IIAFA, Tool-FA	
RQ1			EIs, Video IEI, Tool-EI	SEI, Video ISEI, Tool-SEI
RQ3	Tool Evaluation, n/a, n/a			



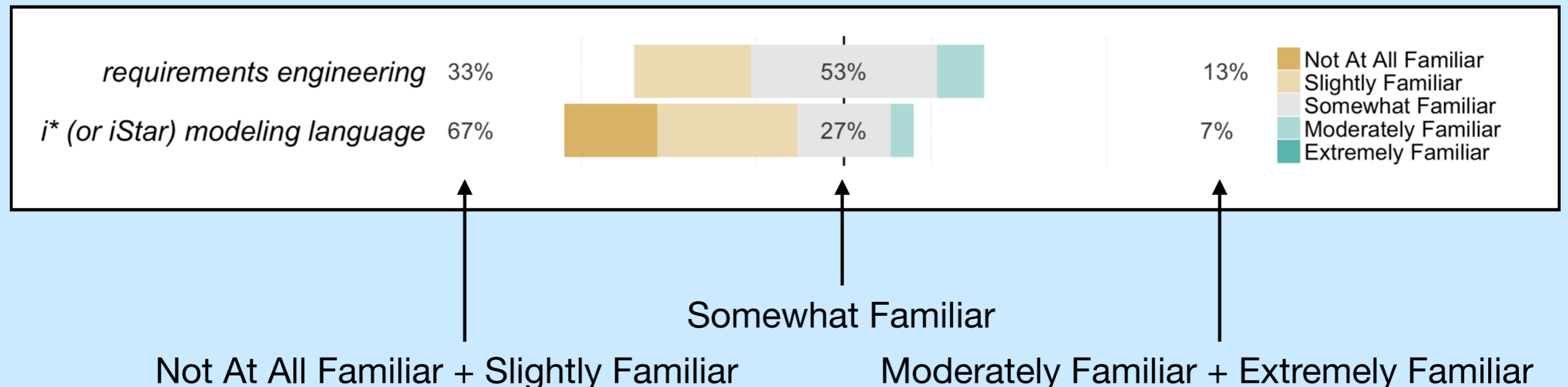
Subject

Researcher

# Subjects

- graduate students (9 Masters, 6 PhD)
- basic understanding of RE & proficient in English
- recruited through mailing list and intro course

Subject self-reported familiarity rating:



# Outline

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- Motivating Example & Background
  - Evolving Intentions (EIs)
  - Simulation over Evolving Intentions (EI-Sim)
  - Tooling: GrowingLeaf
- Study Design
- **Results**
- Implication, Threat to Validity, & Reflections

# RQ0: Baseline Test Between-Subject

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*Research  
Question:*

Do modelers perform similarly on basic cognition tests, given a consistent training protocol?

*Findings:*

- Subjects *performed similarly* on basic cognition tests
- *Enables comparison* between groups in RQ1-RQ3

# RQ1: Evolving Intentions

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*Research Question:*

How do Evolving Intentions (EIs) affect modelers' ability to capture model elements that change over time?

*Findings:*

- Subjects *understood EIs and SEIs*
- Subjects *evaluated intentions* with EIs and SEIs
- *EIs* were found to be *intuitive*

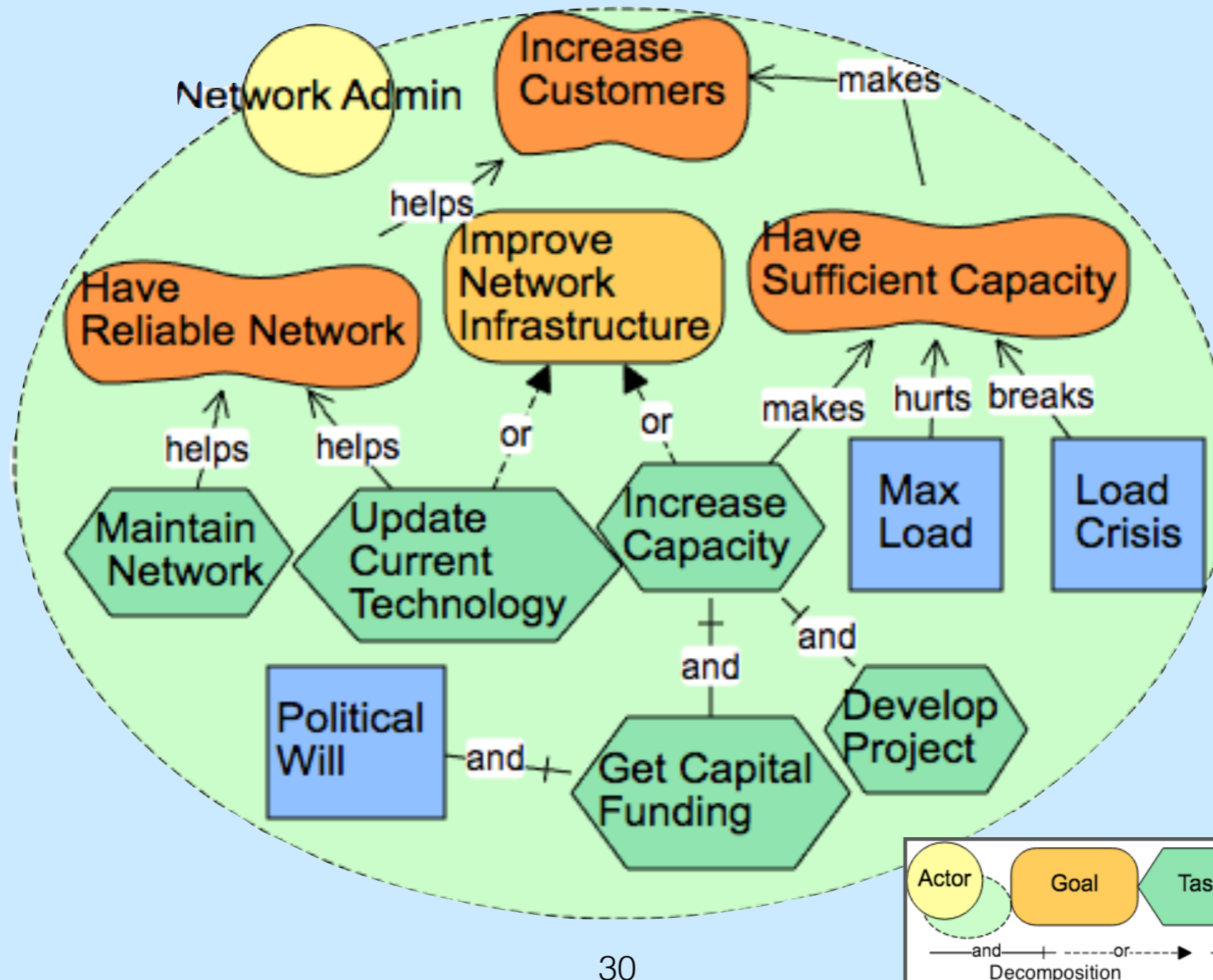
Legend:

EI: Evolving Intention

SEI: Stochastically Evolving Intention

# RQ1: Evolving Intentions

Identify which elements in this model change over time?



# RQ1: Evolving Intentions

Identify which elements in this model change over time?

Elements	LR	A1	A2	A3	A4	A5	CA	CA	CA	B1	B2	B3	B4	B5	CB	CB
Max Load	L	?	I	P	R	P	C			DS	F	R	R	R	I	R
Load Crisis	L	?	R	R	R	P	R			SD	F	R	R	R	R	R
Political Will	L		R	C	R	R	R			R	R	R	R	R	R	
Update Current Technology	L	MP	MP	P	R	I			I		F	P	DS	R		SD
Maintain Network	L	C	MP	C	R	C					F	C	C	R		
Get Capital Funding	N	?	MP	R	I	P		R	SD					R		
Develop Project	L		MP	MP	MP	P			MP			C	C	I		
Increase Capacity	N			R	MP	I		D					UD	R		DS
Have Reliable Network	N	C		R	R	A	?							R		
Improve Network	R			R	?	A		I						R		
Have Sufficient Capacity	N			R	R	A		MP						R		
Increase Customers	R			R	R	A		R						R		

Position: **L**eamf, **R**oot, **N**either

- Group A identified two additional functions.

# RQ1: Evolving Intentions

Identify which elements in this model change over time?

Elements	LR	A1	A2	A3	A4	A5	CA	CA	CA	B1	B2	B3	B4	B5	CB	CB
Max Load	L	?	I	P	R	P	C			DS	F	R	R	R	I	R
Load Crisis	L	?	R	R	R	P	R			SD	F	R	R	R	R	R
Political Will	L		R	C	R	R	R			R	R	R	R	R	R	
Update Current Technology	L	MP	MP	P	R	I			I		F	P	DS	R		SD
Maintain Network	L	C	MP	C	R	C					F	C	C	R		
Get Capital Funding	N	?	MP	R	I	P		R	SD					R		
Develop Project	L		MP	MP	MP	P			MP			C	C	I		
Increase Capacity	N			R	MP	I		D					UD	P		
Have Reliable Network	N	C		R	R	A	?									
Improve Network	R															
Have Sufficient Capacity	N														R	
Increase Customers	R														R	

Primarily Leaf Nodes Identified  
Root and Intermediate Nodes also identified

Position: **L**eam, **R**oot, **N**either

- Group A identified two additional functions.

# RQ1: Evolving Intentions

Identify which elements in this model change over time?

Elements	LR	A1	A2	A3	A4	A5	CA	CA	CA						
Max Load	L	?	I	P	R	P	C								
Load Crisis	L	?	R	R	R	P	R								
Political Will	L		R	C	R	R	R								
Update Current Technology	L	MP	MP	P	R	I			I			F	P	DS	R
Maintain Network	L	C	MP	C	R	C						F	C	C	R
Get Capital Funding	N	?	MP	R	I	P		R	SD						R
Develop Project	L		MP	MP	MP	P			MP			C	C	I	
Increase Capacity	N			R	MP	I		D					UD	R	DS
Have Reliable Network	N	C		R	R	A	?								R
Improve Network	R			R	?	A		I							R
Have Sufficient Capacity	N			R	R	A		MP							R
Increase Customers	R			R	R	A		R							R

• Group A identified Evolving Intention Functions by Name

Position: **L**eamf, **R**oot, **N**either

- Group A identified two additional functions.

# RQ1: Evolving Intentions

Identify which elements in this model change over time?

Elements	LR	A1	A2	A3	A4	A5	CA	CA	CA	B1	B2	B3	B4	B5	CB	CB
Max Load	L	?	I	P	R	P	C			DS	F	R	R	R	I	R
Load Crisis	L	?	R	R	R	P	R			SD	F	R	R	R	R	R
Political Will	L		R	C	R	R	R			R	R	R	R	R	R	
Update Current Technology	L	MP	MP	P	P						F	P	DS	R		SD
Maintain Network											F	C	C	R		
Get Capital Funding														R		
Develop Project												C	C	I		
Increase Capacity				R	MP	I		D					UD	R		DS
Have Reliable Network	N	C		R	R	A	?							R		
Improve Network	R			R	?	A		I						R		
Have Sufficient Capacity	N			R	R	A		MP						R		
Increase Customers	R			R	R	A		R						R		

• Group B refinement of stochastic functions mirror the evolving functions

Position: **L**eam, **R**oot, **N**either

- Group A identified two additional functions.

# RQ2: Simulation over Evolving Intentions

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## *Research Question:*

How does Simulation over Evolving Intentions (EI-Sim) affect modelers' understanding and ability to reason about a goal model with time?

## *Findings:*

- EI-Sim and SEI-Sim improved understanding of *model structure*
- EI-Sim improved *reasoning* about goal models *over time* (significant slower)
- Rep-FA proved difficult for time-focused questions

## Legend:

EI-Sim: Simulation over Evolving Intention

SEI-Sim: Simulation over Stochastically Evolving Intentions

Rep-FA: Repeated Forward Analysis

# RQ2: Simulation over Evolving Intentions

Assume you can sequentially complete both “Build Green Centre” and “Build Small Dump”. Which order is best for the top goals (use simulation/forward analysis to evaluate the alternatives)? Why?

Group A (EI-Sim):

- subjects that used EI-Sim and obtained meaningful results
  - 2 subjects used only the Constant (C) function

Group B (SEI-Sim):

- subjects chose the correct answer looking at the structure of the model

Group C (Rep-FA):

- subjects chose the best alternative and ignored ordering

# RQ2: Simulation over Evolving Intentions

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## *Evaluate RQ2 Completion Times*

### Kruskal-Wallis Rank Sum Test

- *Null Hypothesis*: No difference between groups  
( $p = 0.054$ ) arguably significant

### Dunn's Post-Hoc Pair-wise Comparison Test

- *Group A took significantly longer* (avg. 6 minutes)  
Group B ( $p = 0.0098$ ) & Group C ( $p = 0.045$ )
- no significant difference between Group B & C

# RQ3: GrowingLeaf Tool

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*Research  
Question:*

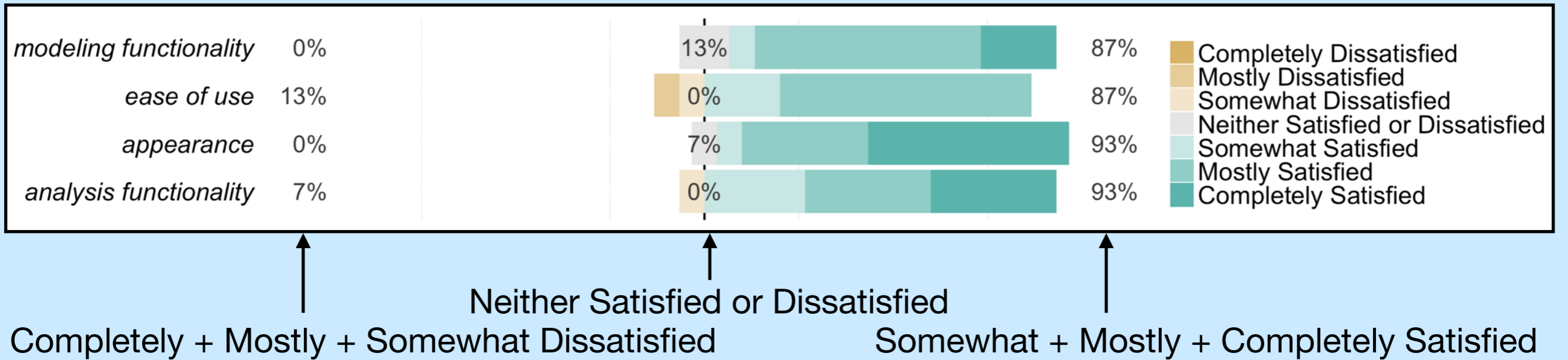
How do modelers evaluate GrowingLeaf after completing modeling and analysis tasks?

*Findings:*

- Subjects *rated GrowingLeaf highly* and found it usable

# RQ3: GrowingLeaf Tool

Rate your level of satisfaction with the tools:



*no significant difference between tool version*

# RQ3: GrowingLeaf Tool

What suggestions or changes would you recommend to the developers of this goal modeling tool?

- Clear all intention evaluation and function labels
- Highlight and unhighlight leaf and root intentions
- Syntax checking

See paper for additional recommendations...

# Summary of Results

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- Els were suitable to the task of identifying and representing intentions over time
- EI-Sim improved the subjects' ability to reason about goal models over time
- GrowingLeaf was found to be effective and usable

# Outline

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  - Evolving Intentions (EIs)
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- Results
- **Implication, Threat to Validity, & Reflections**

# Implications for Research

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- understand why not all Group A subjects used EI-Sim effectively
- subjects paid closer attention to the content of some models but not others



# Implications for Education

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- subjects had difficulty with the Depends link
- SEI-Sim can be used in teaching to help subjects understand
  - the structure of the model
  - forward propagation rules



# Threats to Validity

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## Conclusion Validity

- low sample size  $\Rightarrow$  low statistical power 

## Internal Validity

- self-reported understanding of RE and iStar

## Construct Validity

- evaluation apprehension 

## External Validity

- not generalizable to other populations / domains
- model size not representative

# Reflections

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## **Problem: How to effectively study learning?**

*Ideal: Controlled experiment within a course (with Grades)*

### Our Approach:

- Control for level of past experience 🤔
- Apply Learning Theory
  - Bloom's Taxonomy: remember, understand, apply, analyze, evaluate, and create 😊
- Run multiple pilots to expose tacit learning 😇

# Reflections

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**Problem: Inherent bias studying your own tool/technique**

*Ideal: Get independent researcher to run study*

Our Approach:

- Use third person instead of “my/our” tool/technique



# Reflections

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**Problem: Inherent bias studying your own tool/technique**

*Ideal: Get independent researcher to run study*

Our Approach:

- Use third person instead of “my/our” tool/technique



How would you recommend I improve my tool?

VS.

What suggestions or changes would you recommend to the developers of this goal modeling tool?

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- Use formal experiment protocol:
  - Handouts 😊
  - Videos (with non-researcher’s voice over) 😇

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- Use third person instead of “my/our” tool/technique 😊
- Use formal experiment protocol:
  - Handouts 😊
  - Videos (with non-researcher’s voice over) 😊
- Use formal data analysis protocol:
  - Understand data analysis procedure before study 🤔
  - Analyze data after collection is complete 👧👧
  - Use non-parametric statistics (unknown distribution) 😊

# Supplemental Information

## Supplementary Information for “Modeling and Reasoning with Changing Intentions: An Experiment”

In this paper, we report on a between-subjects experiment we conducted with fifteen graduate students familiar with requirements engineering. The experiment investigates the effectiveness and usability of Evolving Intentions, Simulation over Evolving Intentions, and GrowingLeaf.

A. M. Grubb and M. Chechik. [Modeling and Reasoning with Changing Intentions: An Experiment](#). 2017 IEEE 25th International Requirements Engineering Conference (RE), 2017. © IEEE 2017.

This page discusses supplemental material. It is recommended that you read the paper prior to continuing here.

### Materials

Here are the study materials.

Study Protocol:

- [Consent Form](#).
- [Study Questions](#).
- [Prize Draw Form](#).
- [Study Follow-up Form](#).

Models:

- Trusted Computing Model: [.png .json](#)
- Network Administrator Model: [.png .json](#)
- Waste Management Model: [.png .json](#)

Videos and Handouts:

- [Video 0A. iStar Handout](#).
- [Video 0B. Forward Analysis Handout](#).
- [Video IEL. Evolving Intentions Handout](#).
- [Video ISEI. Stochastically Evolving Intentions Handout](#).
- [Video IIEI](#).
- [Video IISEI](#).
- [Video IIAFA](#).

Tool Versions:

- [GrowingLeaf-EI-Sim \(Tool-EI\)](#).
- [GrowingLeaf-SEI-Sim \(Tool-SEI\)](#).
- [GrowingLeaf-Forward Analysis \(Tool-FA\)](#).

R Files:

- [.R File](#)

Subject Recruitment:

- [Study advertisement email](#).
- [Graduate class Message Board advertisement](#).
- [Emails to schedule experiment](#).

<http://www.cs.toronto.edu/~amgrubb/archive/RE17-Supplement>

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*Useful for other tool  
or modeling studies*

# Summary

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## Results:

- Evolving Intentions were intuitive
- EI-Sim increased the subjects' understanding and produced meaningful results
- GrowingLeaf was found to be usable

## Future work will improve this study:

- larger sample size and larger models
- different populations and domains

Study methodology and materials available for reuse

# Questions?

# Modeling and Reasoning with Changing Intentions: An Experiment

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Tool:

<http://www.cs.toronto.edu/~amgrubb/growing-leaf/>