Achieving greater circularity in the construction and demolition industry: A Greater Sydney case study

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Introduction

Circular Economy

An economic system that aims to keep resources in use for as long as possible (Hofmann, 2019).

The current:

Only around 9% of all the materials consumed were recycled in 2022 (Neuhold, 2022).

- Designing out waste and pollution (Bao, 2023).
- Regenerating natural systems ((Bianchi & Cordella, 2023).

Circular Construction

- Applies the principles of the circular economy to create a closed-loop system for construction industry (Ghaffar et al., 2020).

Introduction

Recovery in NSW

- Resource recovery rate: 67.1%.
- Recycling rate: 64.7%.
- Recovery rate for C&D waste: 79.6%.
- C&D generates the most non-recycled waste: 1.7m tonnes/y.

(Australian Government Department of Climate Change Energy the Environment and Water, 2022)

Concrete consumption:

- 29 million cubic meters per year (Cement Concrete & Aggregates Australia, 2023).

Mostly used type

- Regular strength concrete.
- 20 MPa(megapascal) to 40 MPa (typically around 25 MPa).
- Building foundations, slabs, and walls.

(Mohammadi and South, 2017)

Literature review & Research gaps

Current research

- Recycled concrete applications (Economic and environmental benefits)
- Importance of Transportation management

Research gap

- Lack of studies examining the relationship between recycling cost, landfill cost, logistics cost, recycling and landfill rate.

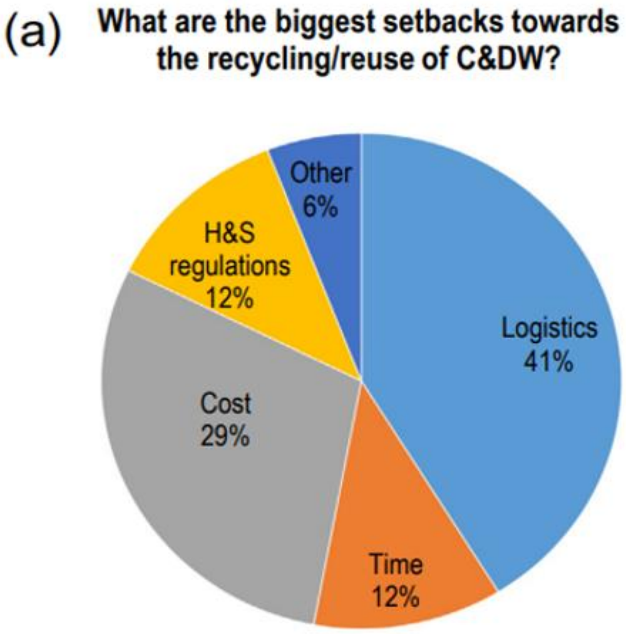

Fig 1 Bottleneck in efficient recycling and re-use in UK as revealed from questionnaire

(Ghaffar, Burman and Braimah, 2020)

Methodology

System Dynamics

- Analyses complex systems and their change over time (Jones, 2014).
- Uncover system properties and identify crucial variables (Karnopp, 2012).
- Good for social, economic, ecological, and engineering systems that involve feedback loops, delays, and nonlinear relationships

To build a SD model

- Define System Boundaries
- Identify Key Components and Feedback Loops
- Create Computer-based Model using Vensim
- Run Simulations
- Analyze Results

Objective

- Understand the relationship between recycling cost, landfill cost, and logistics cost

Focus

- Construction industry in Sydney

Data Sources

- Academic literature
- Industry reports
- Expert from industry

Model formulation

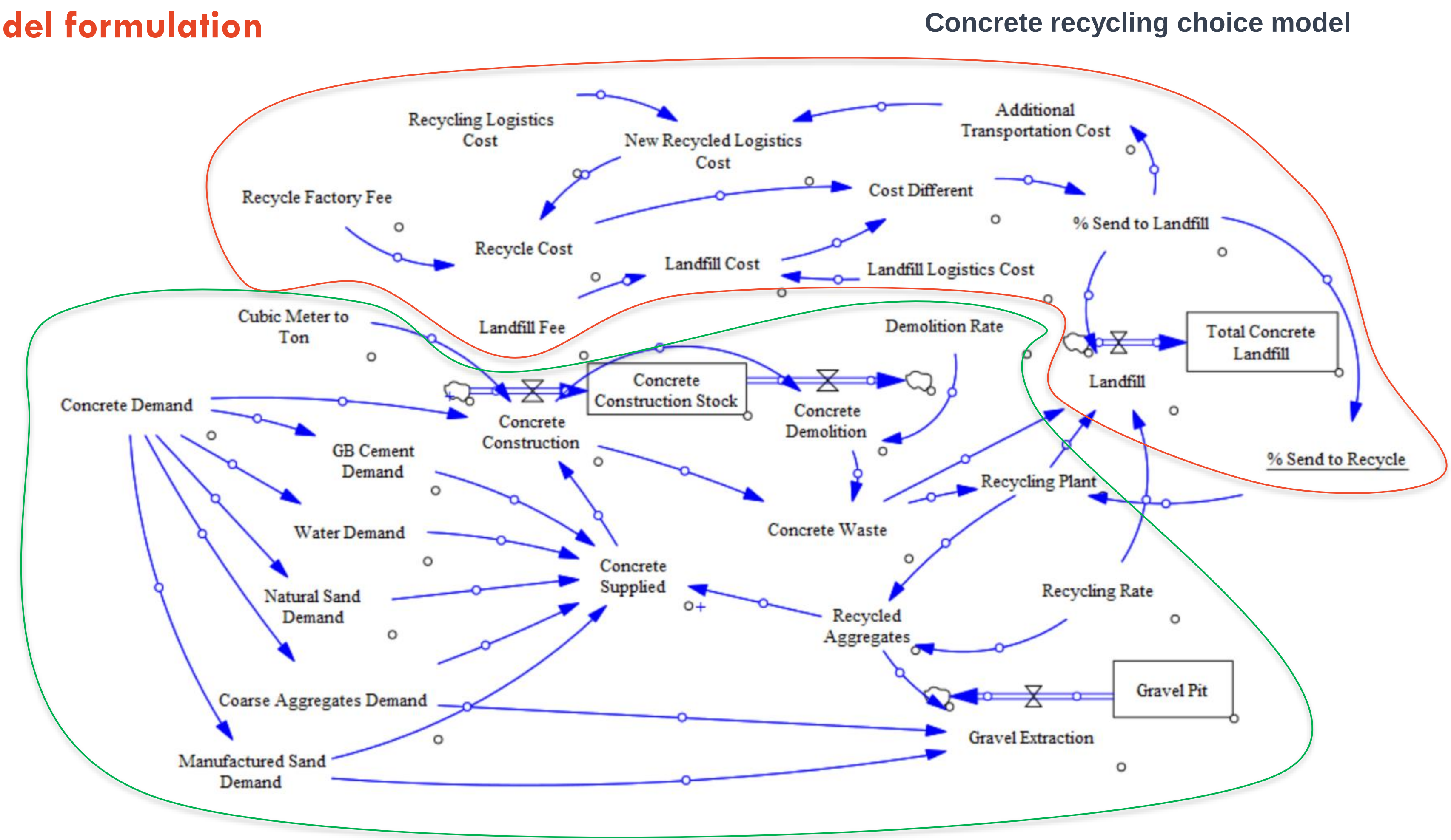

Figure 2 Sydney concrete supply chain

Model formulation

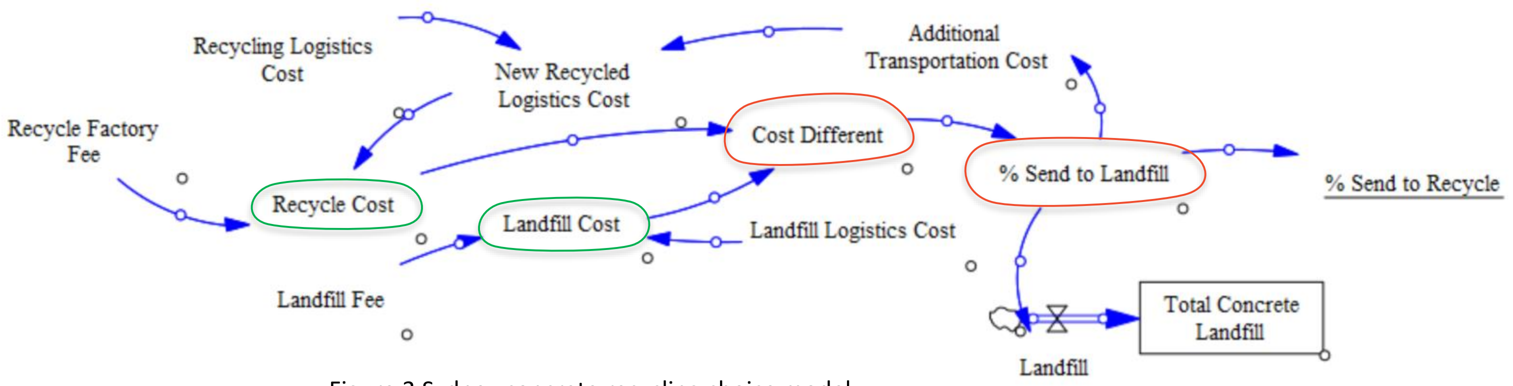

Figure 3 Sydney concrete recycling choice model

Additional transportation cost

- Rise in landfill fee prompts shift to recycling.
- Companies switch from previous short landfill routes to longer recycling routes.
- Recycling becomes financially prudent despite higher transport costs.

Model formulation

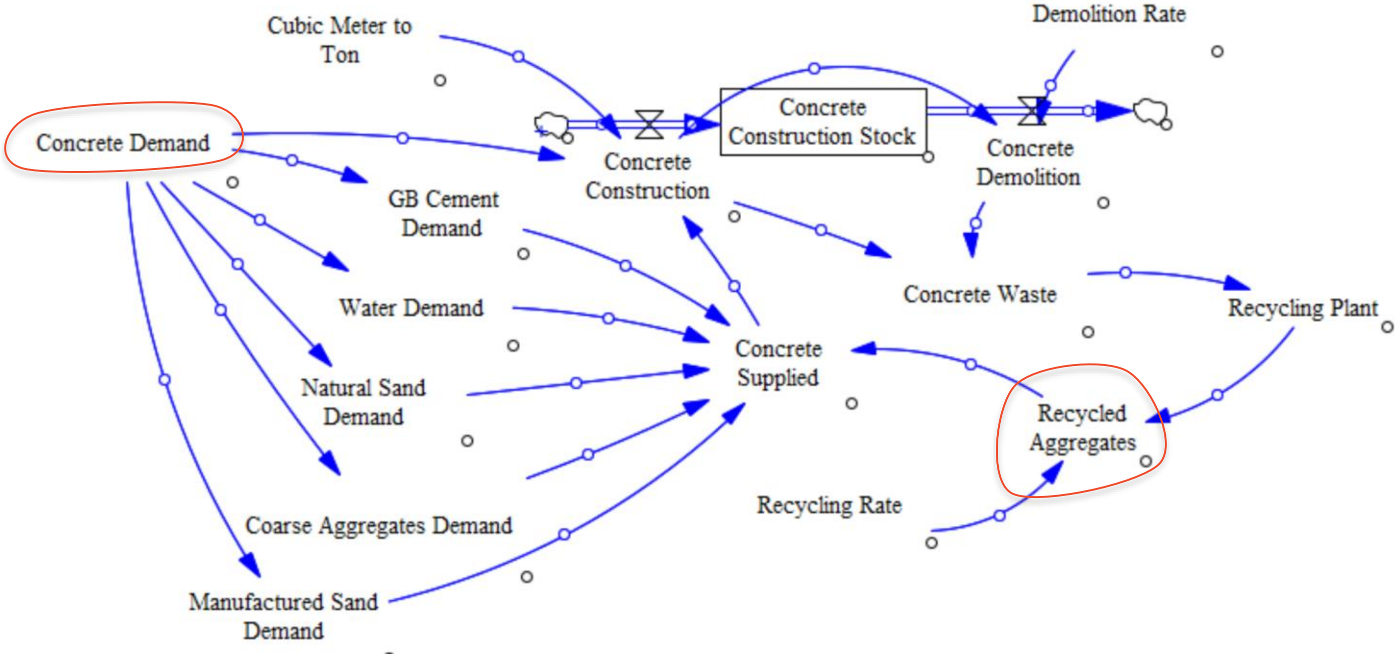

Figure 4 Sydney concrete production model

Model formulation

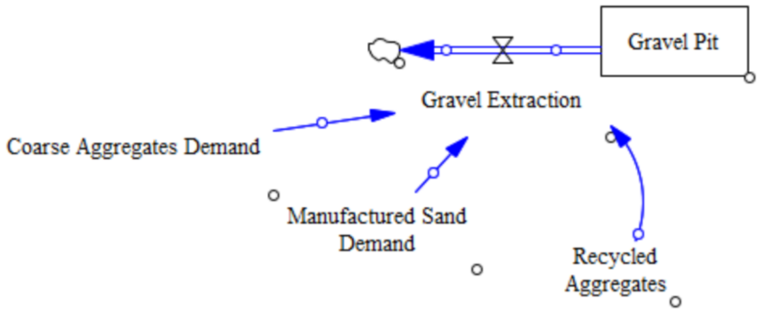

Figure 5 Gravel pit extraction

Model formulation

Variables	Type	Unit	Equations
Concrete Demand	Data	m^3	/
GB Cement Demand	Auxiliary	Ton	(240*Concrete Demand)/1000
Water Demand	Auxiliary	Ton	(165*Concrete Demand)/1000
Natural Sand Demand	Auxiliary	Ton	(Concrete Demand*380)/1000
Coarse Aggregates Demand	Auxiliary	Ton	(1000*Concrete Demand)/1000
Manufactured Sand Demand	Auxiliary	Ton	(450*Concrete Demand)/1000
Concrete Supplied	Auxiliary	m^3	GB Cement Demand/240+Water Demand/165+Natural Sand Demand/380+(Coarse Aggregates Demand-Recycled Aggregates/1000)+Recycled Aggregates/1000+Manufactured Sand Demand/450
Concrete Construction	Auxiliary	Ton	(MIN(Concrete Demand, Concrete Supplied))*Cubic Meter to Ton
Cubic Meter to Ton	Constant		2.235
Concrete Construction Stock	Level	Ton	Concrete Construction-Concrete Demolition
Concrete Demolition	Auxiliary	Ton	Concrete Construction*Demolition Rate
Demolition Rate	Auxiliary		0.457666*0.5
Concrete Waste	Auxiliary	Ton	Concrete Demolition+1e-07*Concrete Construction
Recycling Plant	Auxiliary	Ton	"% Send to Recycle"*Concrete Waste
Recycled Aggregates	Auxiliary	Ton	Recycling Plant*Recycling Rate
Recycling Rate	Constant		0.9
Gravel Extraction	Auxiliary	Ton	Manufactured Sand Demand+Coarse Aggregates Demand-Recycled Aggregates
Gravel Pit	Level	Ton	-Gravel Extraction
Recycle Factory Fee	Constant	\$	80
Recycling Logistics Cost	Constant	\$	445
Recycle Cost	Auxiliary	\$	New Recycled Logistics Cost+Recycle Factory Fee
New Recycled Logistics Cost	Auxiliary	\$	Recycling Logistics Cost+Additional Transportation Cost
Additional Transportation Cost	Auxiliary	\$	(1-"% Send to Landfill")*30
Landfill Fee	Constant	\$	147
Landfill Cost	Auxiliary	\$	Landfill Fee+Landfill Logistics Cost
Landfill Logistics Cost	Constant	\$	450
Cost Different	Auxiliary	\$	Recycle Cost-Landfill Cost
% Send to Landfill	Auxiliary		1/(1+ exp(-(1.5869 - (-0.0829612) * Cost Different)))
% Send to Recycle	Auxiliary		1-"% Send to Landfill"
Landfill	Auxiliary		Concrete Waste*"% Send to Landfill"+(1-Recycling Rate)*Recycling Plant
Total Concrete Landfill	Level		Landfill

Table 1 Equations in SD model.

Scenario Result & Discussion

Time	/	/	/	/	At month 120	At month 120	At month 120	At month 120
Unit	$	$	/	/	Million ton	/	Million ton	/
Scenarios	**Recycling logistic cost**	**Landfill logistic cost**	**Sent to recycle**	**Sent to landfill**	**Total landfill**	**Total landfill / base**	**Total gravel extraction**	**Total gravel extraction / base**
Landfill logistic cost increase 10%	445	495	99.60%	0.40%	4.09	53%	76.74	95.54%
Recycling logistic cost increase 10%	489.5	450	41.58%	58.42%	24.78	323%	97.44	121.31%
Landfill logistic cost decrease 25%	445	337.5	0.70%	99.30%	39.35	514%	112	139.44%
Recycling logistic cost decrease 25%	333.75	450	100.00%	0.00%	4.09	53%	76.62	95.39%
Both cost decrease 50%	222.5	225	87.97%	12.03%	8.25	108%	80.91	100.73%
Both cost increase 100%	890	900	92.42%	7.58%	6.66	87%	79.32	98.75%
Base	445	450	89.64%	10.36%	7.66	100%	80.32	100.00%

Scenario Result & Discussion

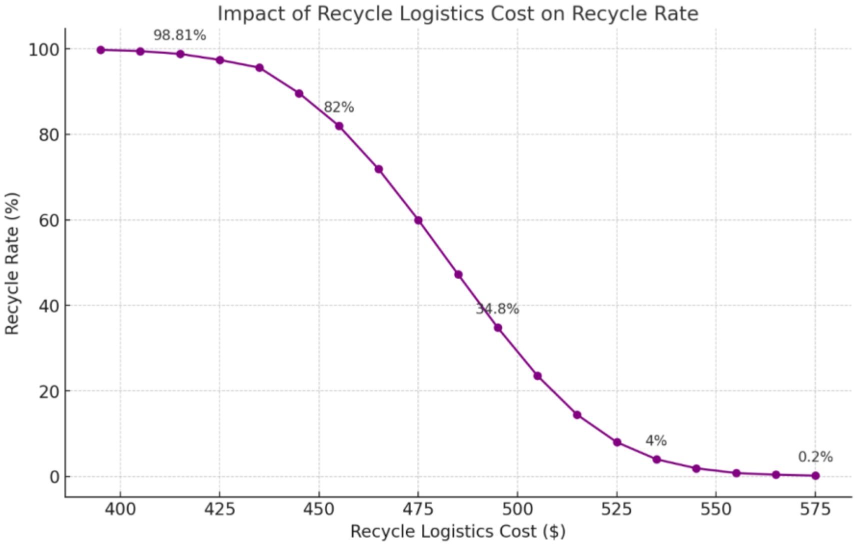

Figure 6 Impact of Recycle Logistics Cost on Recycle Rate

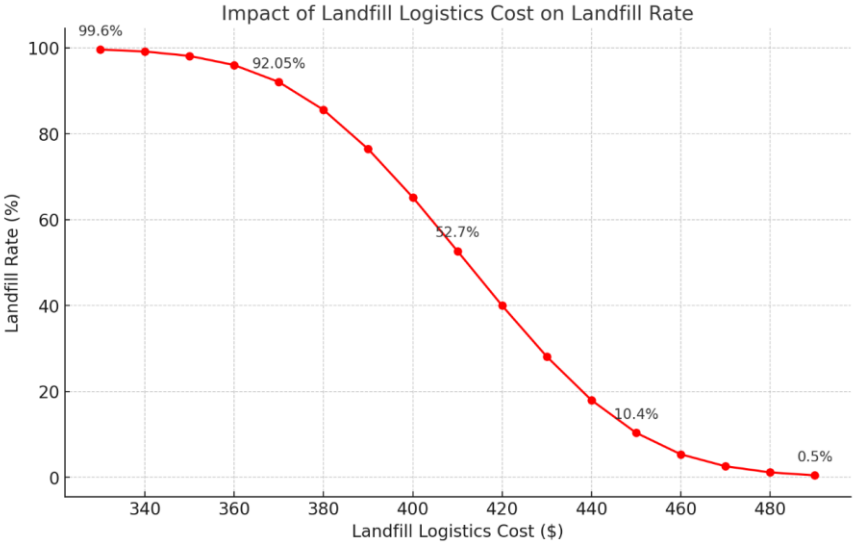

Figure 7 Impact of Landfill logistics cost on Landfill Rate

Scenario result & Discussion

Dynamic relationship Identification

- Uncovered a nonlinear dynamic relationship between recycling cost, landfill cost, recycling rate, and landfill rate.

Importance of Recycling and Landfill Cost Ratio:

- Highlighted the need to maintain a specific cost ratio between recycling and landfill.
- Can inform economic incentives or regulations to encourage recycling.
- Find optimal cost ratios and predictive analytics in recycling.

Covering Poor Recycling Supply Chain Efficiency:

- Identified that good cost ratio management can offset poor logistic supply chain efficiency.

Logistics Cost Significance:

- Emphasized the important role of logistics costs in recycling.
- Recycling caused by higher landfill fee will increase the total recycling transportation cost, because companies were forced to choose the cheaper but longer route.
- May lead to efforts to reduce these costs through optimization and technological investments.

On going research

- Location selection

- Traffic prediction

- Stake holder analysis

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