European Spreadsheet Risks Interest Group

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@VerifyVeracity

EuSpRIG 2013

IRM Models

Challenges

Conceptual Approach

Methodology

Model Extraction

Visualise

Model Metrics

Discipline Coupling

Sensitivity Ana

Conclusions

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Multidisciplinary Engineering Models: Methodology and Case Study in Spreadsheet Analytics

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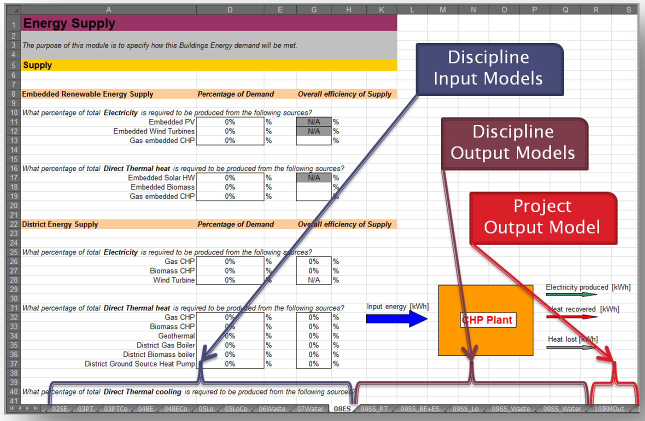
We are an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services.

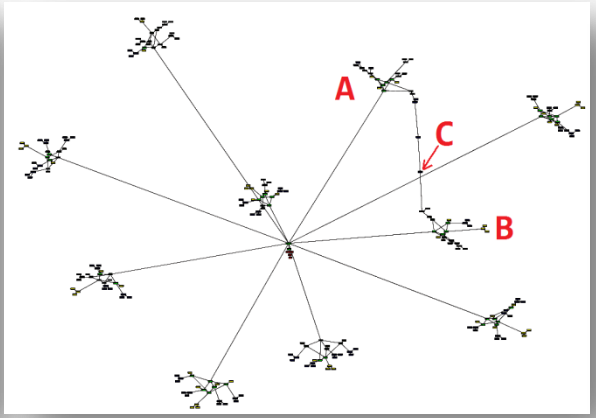
We shape a better world

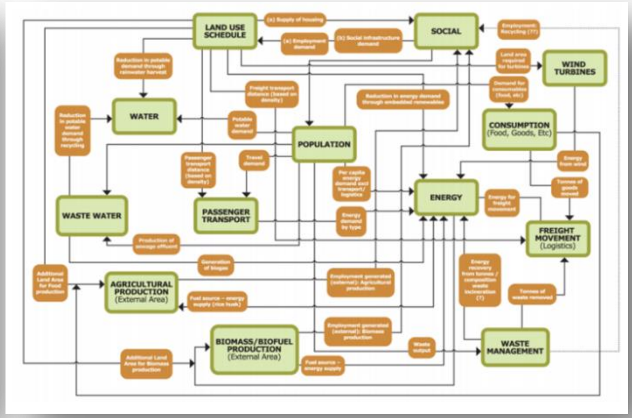
foresight

My Goal

To demonstrate how **spreadsheet analytics** can give **insight** into the **conceptual model** of **multidisciplinary engineering** models





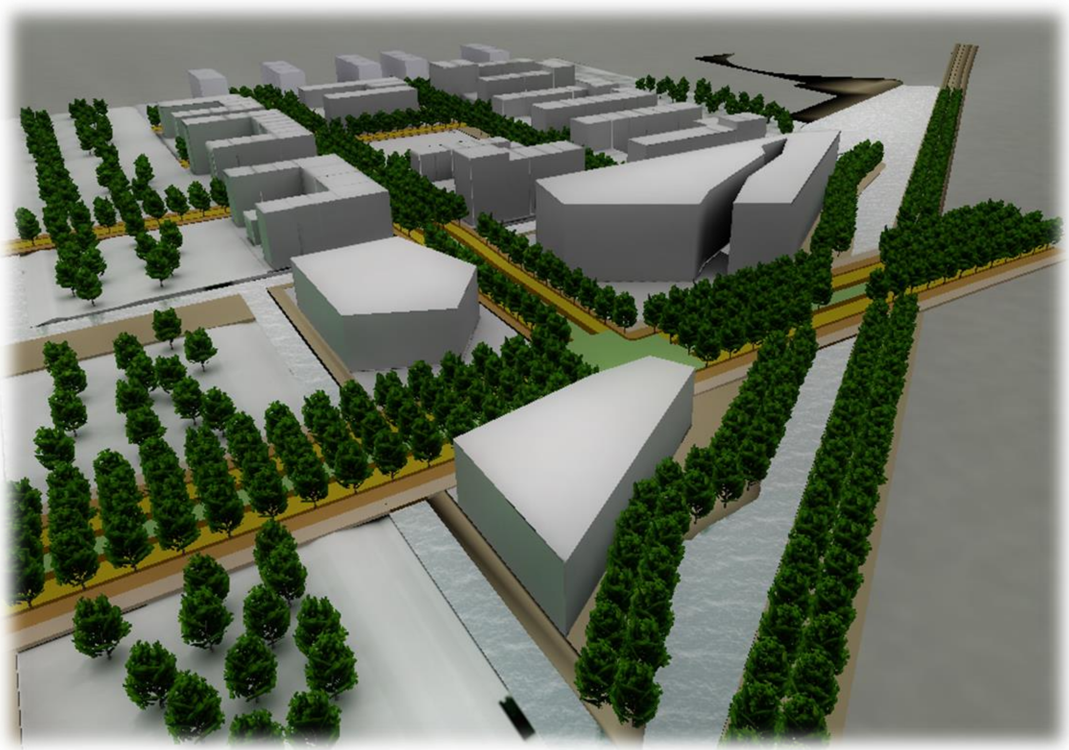


Spreadsheet > Analytics > Conceptual Model

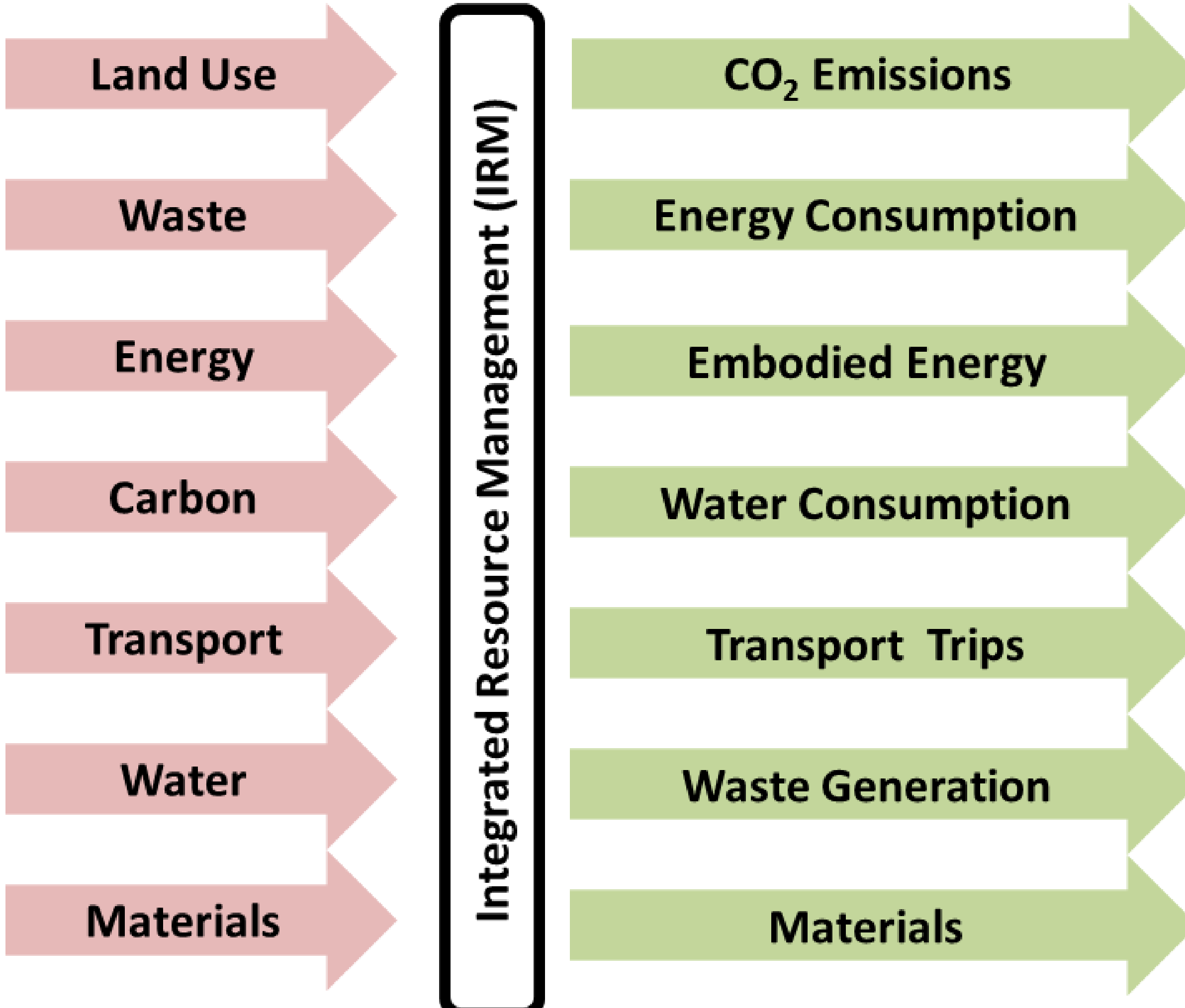
Context – Urban Masterplanning

Design of a new campus, suburb or city at a high level of abstraction

- Multiple Disciplines
- Multiple Objectives
- Multiple Models

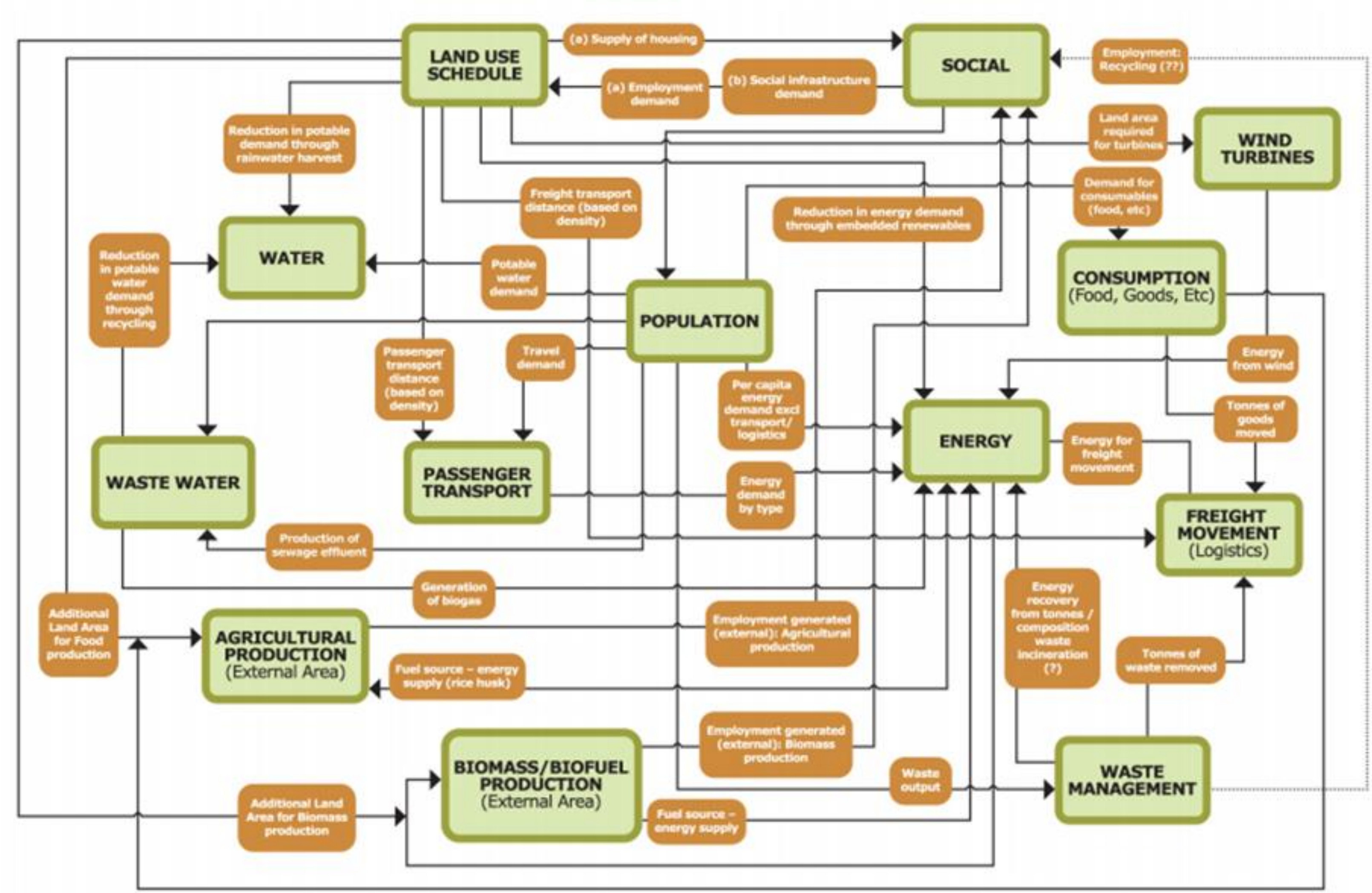


Integrated Resource Management



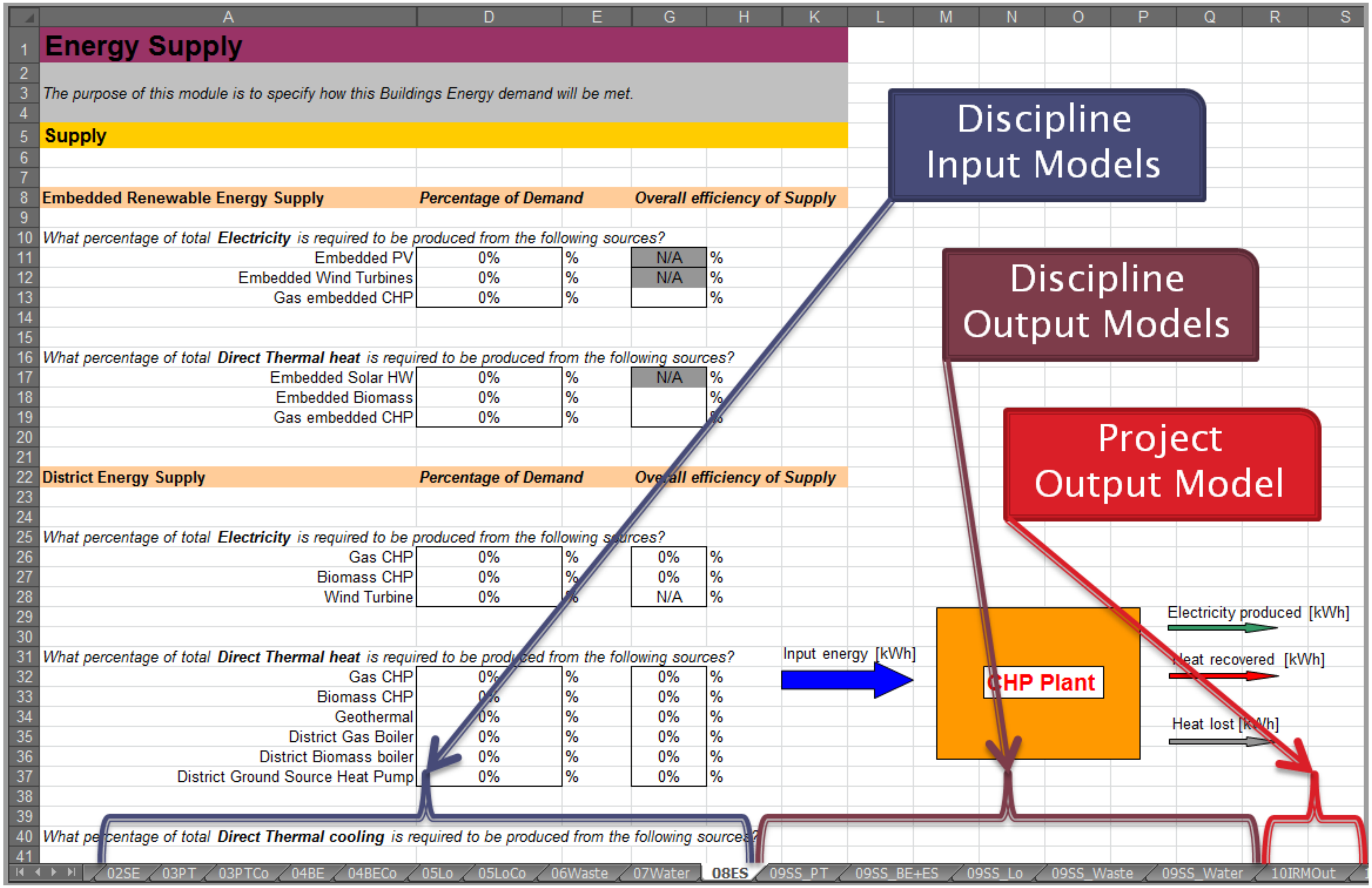
Ayaz E. and Levitas J. Spatially linked integrated resource management (IRM): A tool to inform eco-city planning. In *Proceedings of the 8th International Eco-city Conference, Eco-city 08*, December 2008

IRM Conceptual Model



Page J., Grange N. and Kirkpatrick N. The integrated resource management (IRM) model - guidance tool for sustainable urban design. In *25th Conference on Passive and Low Energy Architecture, PLEA08*, October 2008

IRM Spreadsheet Model



Challenges in IRM analyses

- Interdisciplinary – communication, disparity of data & assumptions
- Large data requirements
- Complexity of modelling

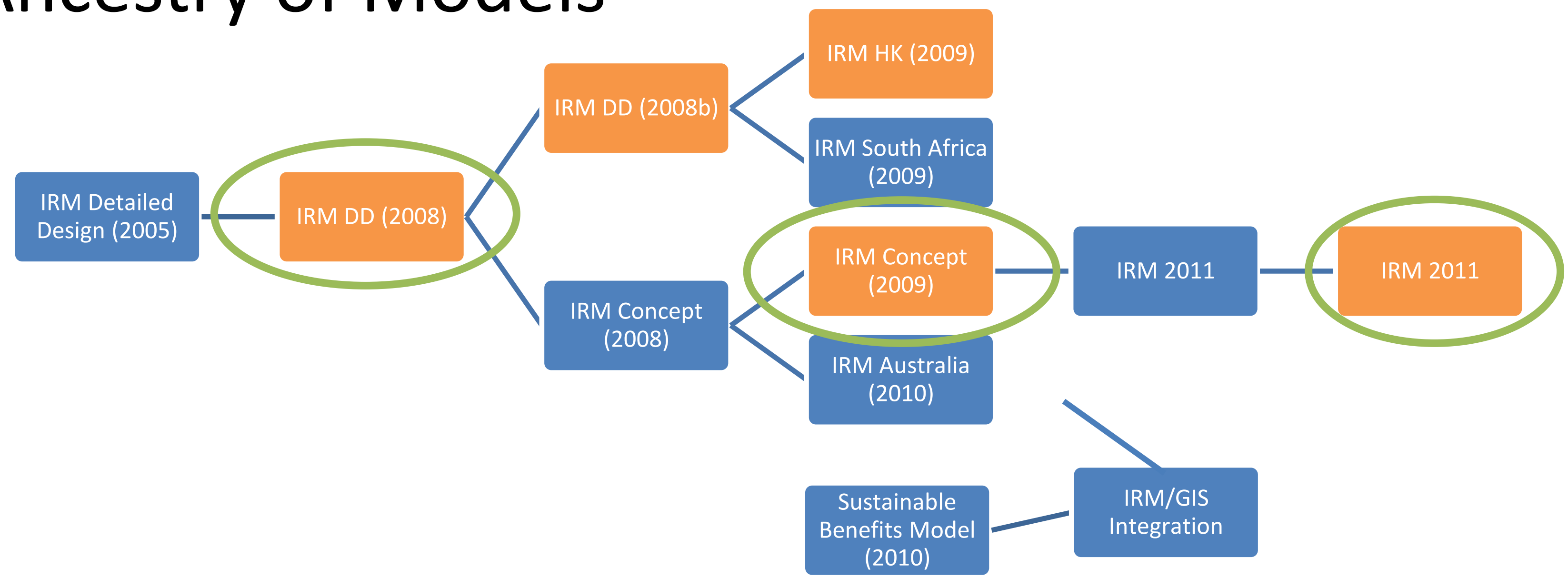
Formulas Used in IRM models		
IRM 2008	IRM 2009	IRM 2011
1,234 Cells 2,360 References	2,357 Cells 3,404 References	37,926 Cells 253,222 References

Challenges in IRM analyses

- Models too **broad** => model evolution
- Models too **narrow** => model evolution

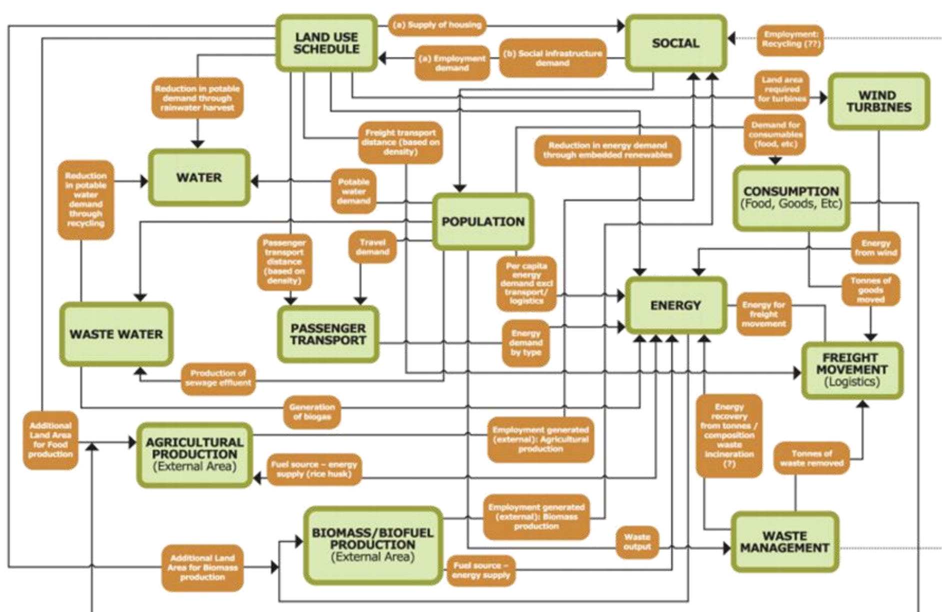
Challenges in IRM analyses

- Models too broad => model evolution
- Models too narrow => model evolution
- **<u>Constant difficult project adaptation</u>**
- Ancestry of Models



Challenges in IRM analyses

- Cause & Effect unclear
- Validation (model vs real world)
- Verification (spreadsheet vs model)
- Difficulty of optimisation



Scientific Model Making

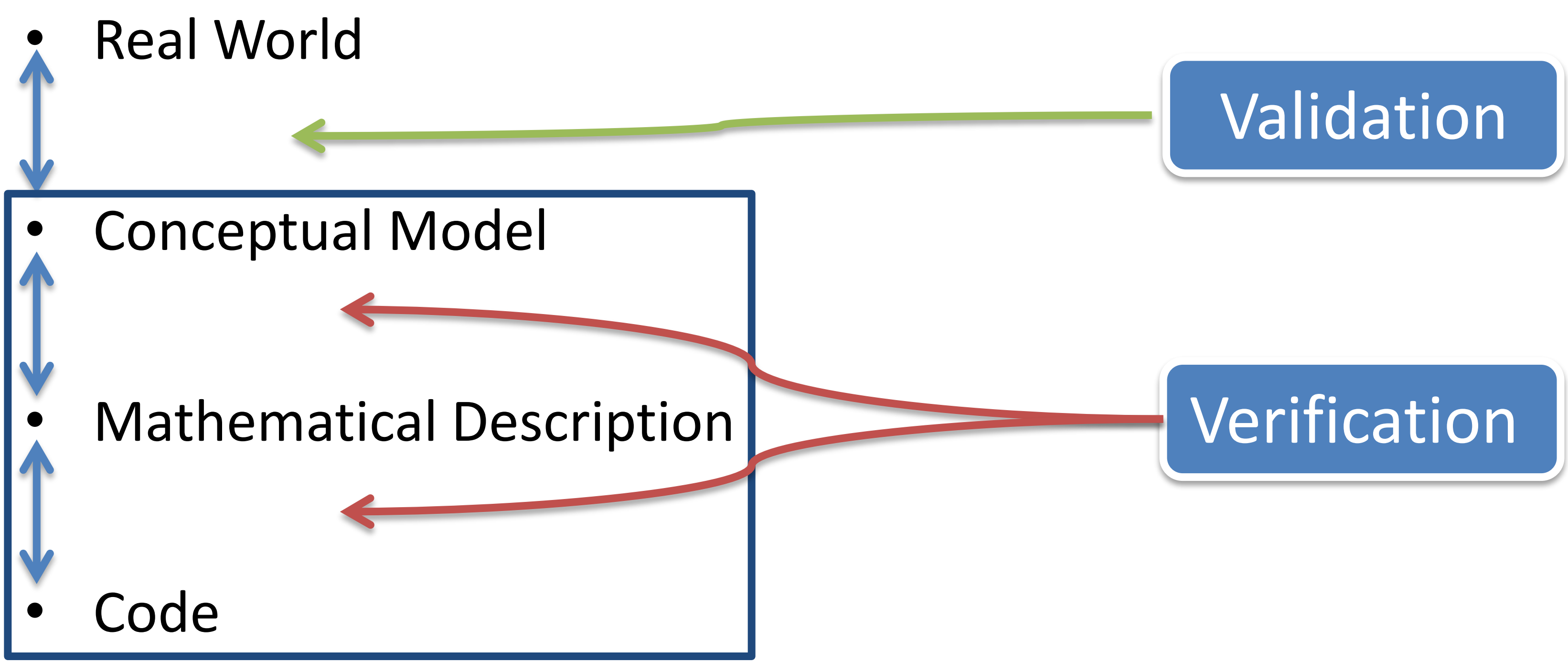
Scientific Model

- Real World
- Conceptual Model
- Mathematical Description
- Code

http://www.easterbrook.ca/steve/?p=2030

Verification / Validation

Scientific Model



http://www.easterbrook.ca/steve/?p=2030

Spreadsheets

Scientific Model

- Real World
- Conceptual Model
- Mathematical Description
- Code

Excel Models

- Real World
- Conceptual Model
- Excel Formulas

- **The excel model has become the math and the code**

Spreadsheets

Scientific Model

- Real World
- Conceptual Model
- Mathematical Description
- Code

Excel Engineering Model

- Real World
- Excel Model Formulas

- **The excel model has become the conceptual model**

Spreadsheets

Scientific Model

- Real World
- Conceptual Model
- Mathematical Description
- Code

Excel Engineering Model

- Real World
- Excel Model Formulas

- **What can code metrics tell practitioners about their conceptual model?**
- **Particularly in multi-disciplinary models**

Methodology*

1. **Obtain** - Model and project objectives.
2. **Define** - Key Performance Indicators (KPIs) of interest

* Liang , H. and Birch, D. (2011), “Extraction and Analysis Methodology for Supporting Complex Sustainable Design”, Proceedings of the 18th International Conference on Engineering Design (ICED11).

Methodology*

1. **Obtain** - Model and project objectives.
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4. **Analyse -Visualise** - Aid comprehension & show cause & effect.
5. **Analyse - Metrics** - For insight into model composition.

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5. **Analyse - Metrics** - For insight into model composition.
6. **Optimise** - Set variable ranges to formalise implicit knowledge enabling sensitivity analysis to give insight and focus optimisation effort.

* Liang , H. and Birch, D. (2011), "Extraction and Analysis Methodology for Supporting Complex Sustainable Design", Proceedings of the 18th International Conference on Engineering Design (ICED11).

Model Extraction

- Recursive extraction, parsing and evaluating of cell formulas from KPI's backwards
- Slice model to reduce complexity

Model Extraction

- Modified version of http://ncalc.codeplex.com
- It's a .Net expression language in C#
- Re-implemented functions (sum, lookup,…)
- Allows classification of link type

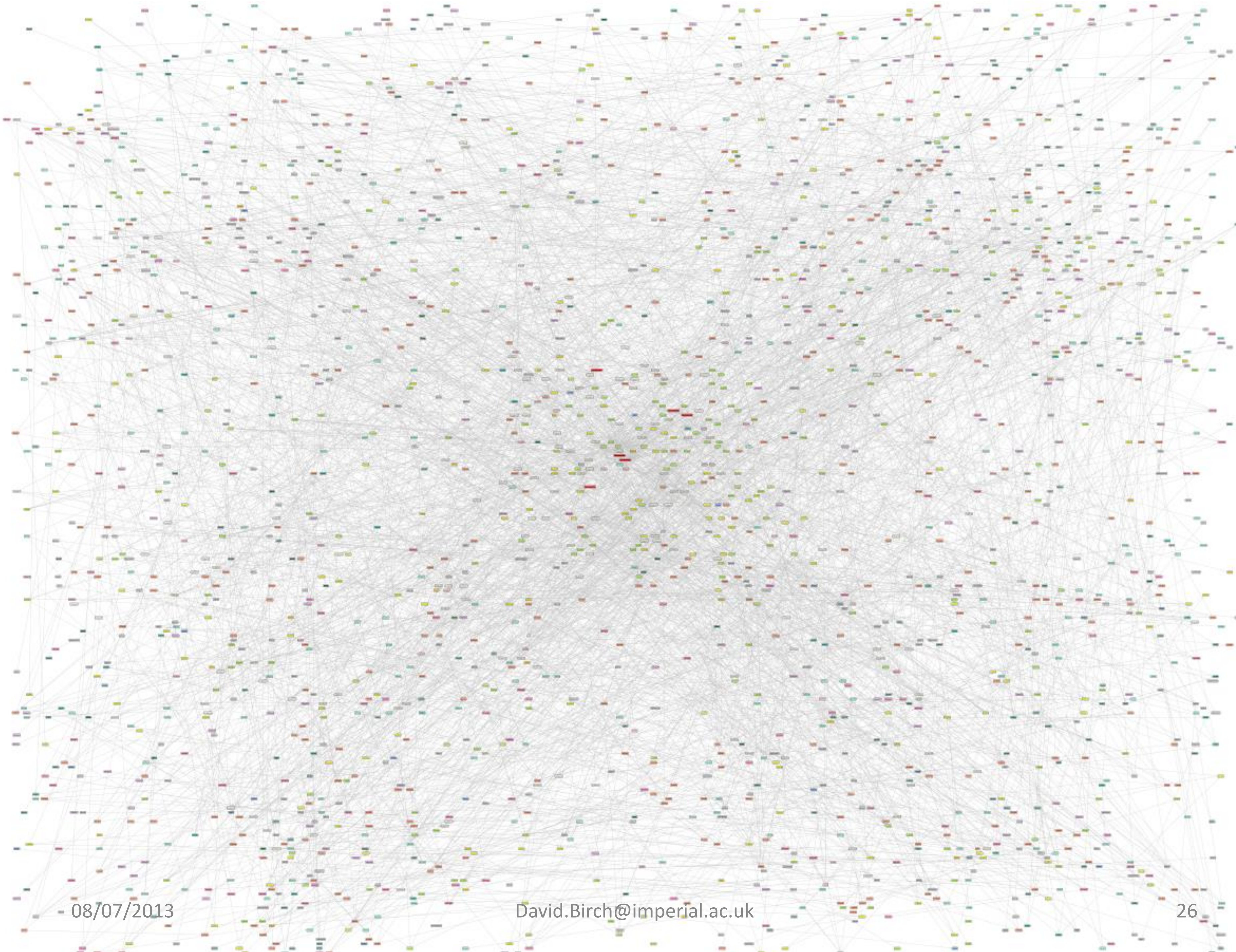
- Now bug compatible with Excel

	A	B
1	apples	oranges
2	2	4
3	3	5
4	=++A1++A2++A3	=+++SUM(B1:B3)

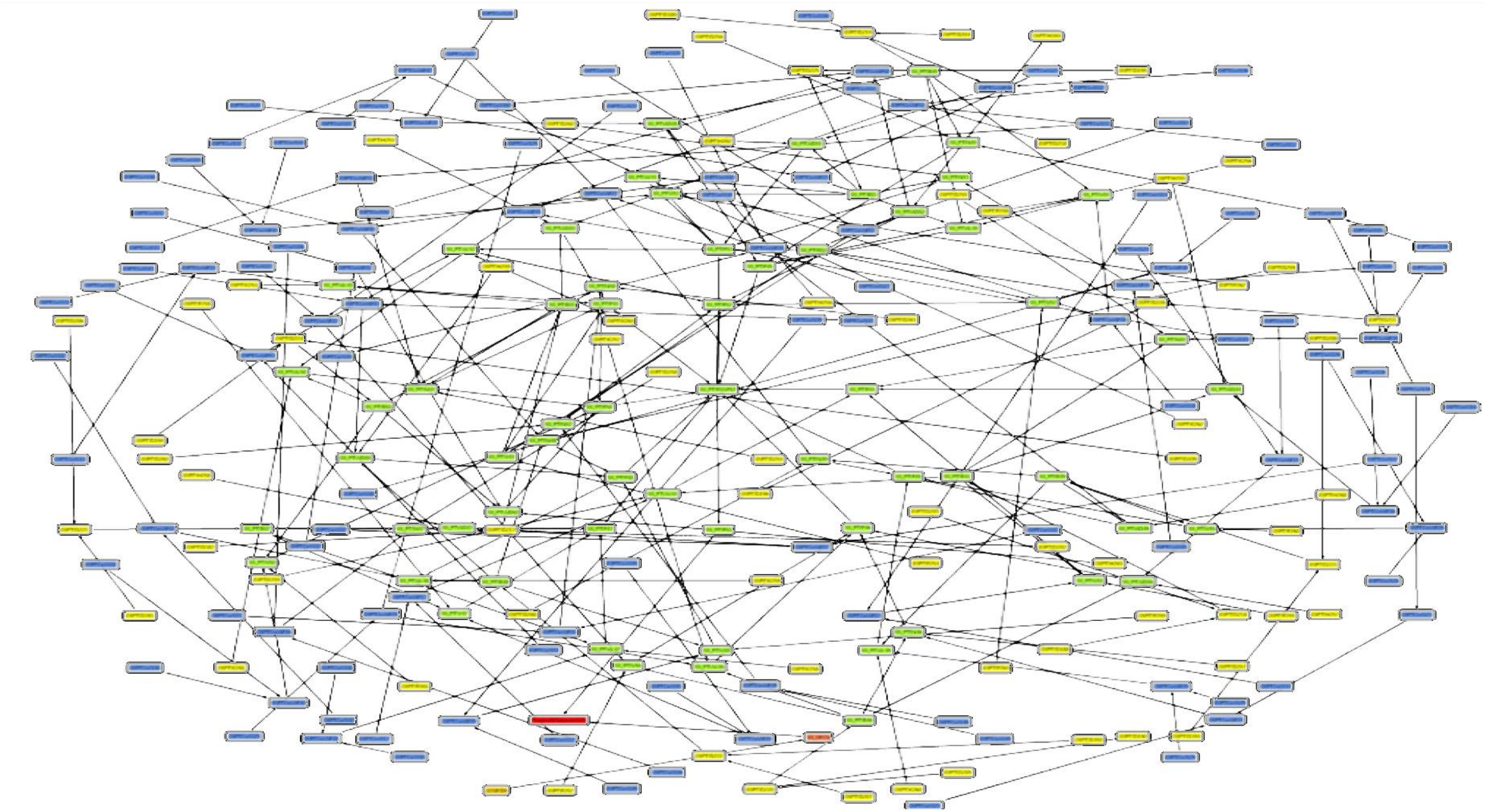
Model Extraction

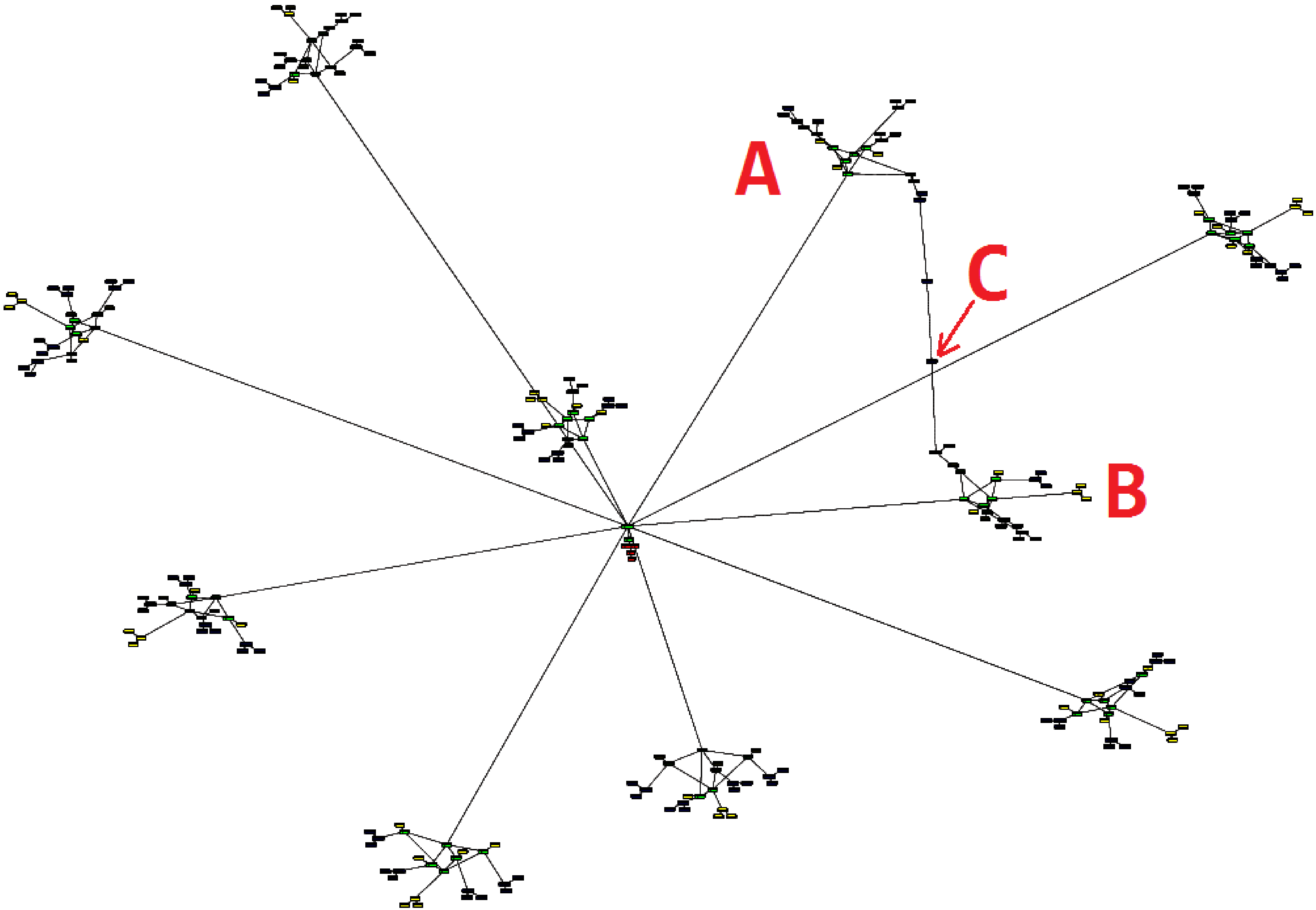
```
Expression e = new Expression("Round(Pow(Pi, 2) + Pow([Pi2], 2) + X, 2)");

  e.Parameters["Pi2"] = new Expression("Pi * Pi");
  e.Parameters["X"] = 10;

  e.EvaluateParameter += delegate(string name, ParameterArgs args)
    {
      if (name == "Pi")
      args.Result = 3.14;
    };

  Debug.Assert(117.07 == e.Evaluate());
```

	A	B
1	apples	oranges
2	2	4
3	3	5
4	=++A1++A2++A3	=+++SUM(B1:B3)
	#VALUE!	9



Model Complexity

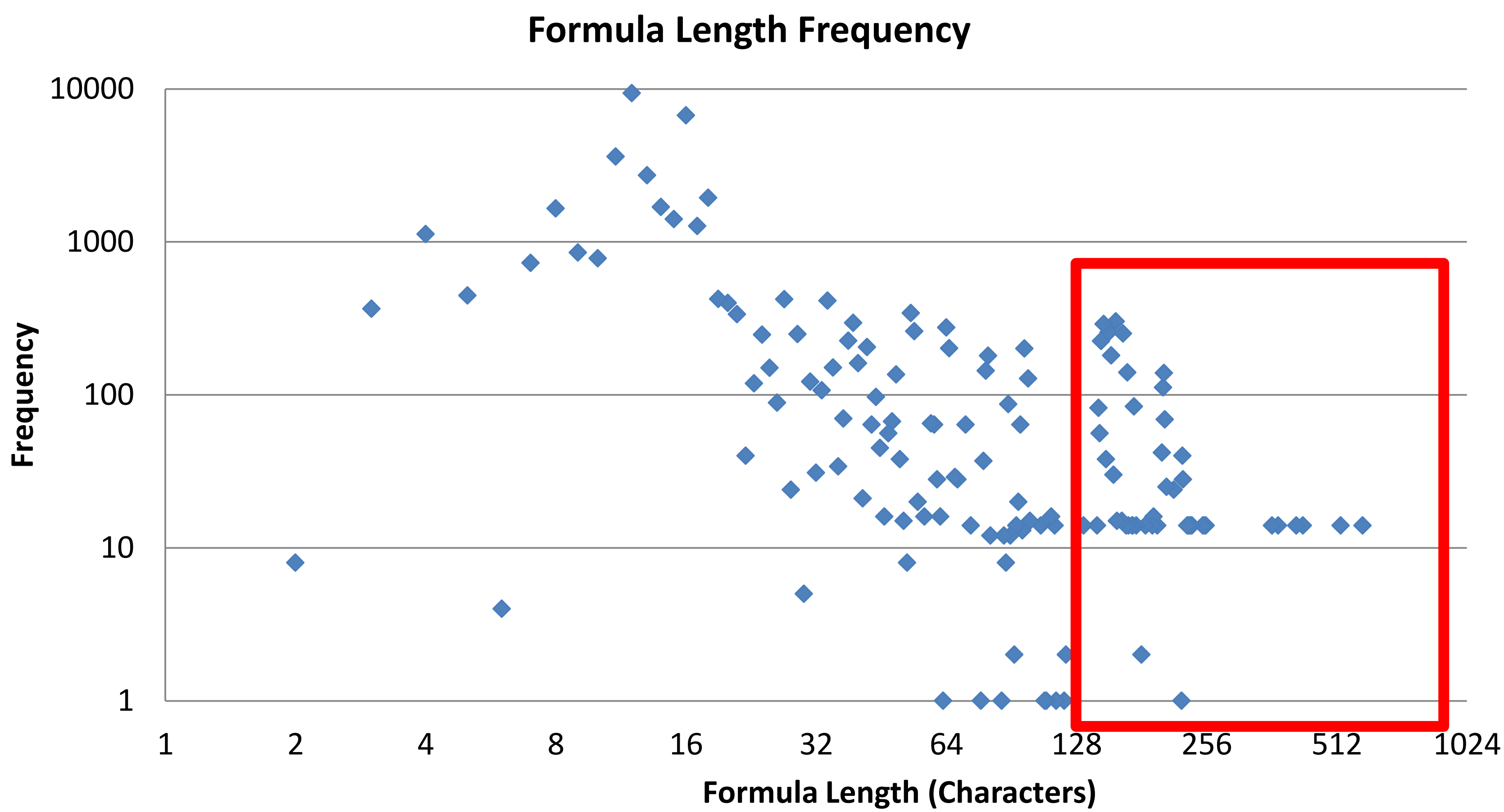



A
C
B

Model Metrics

Formulas Used in IRM models					
IRM 2008		**IRM 2009**		**IRM 2011**	
1,234 Cells **2,360 References**		**2,357 Cells** **3,404 References**		**37,926 Cells** **253,222 References**	
SUM	79	SUM	176	IF	5250
		IF	99	MATCH	2714
		TYPE	81	HLOOKUP	2714
				ROUNDUP	1717
				ISERROR	1357
				SUM	1223
				VLOOKUP	198
				SUMIF	78
				AND	57
				ISNUMBER	28
				Misc	7

Formula Length



“Magic” Constants

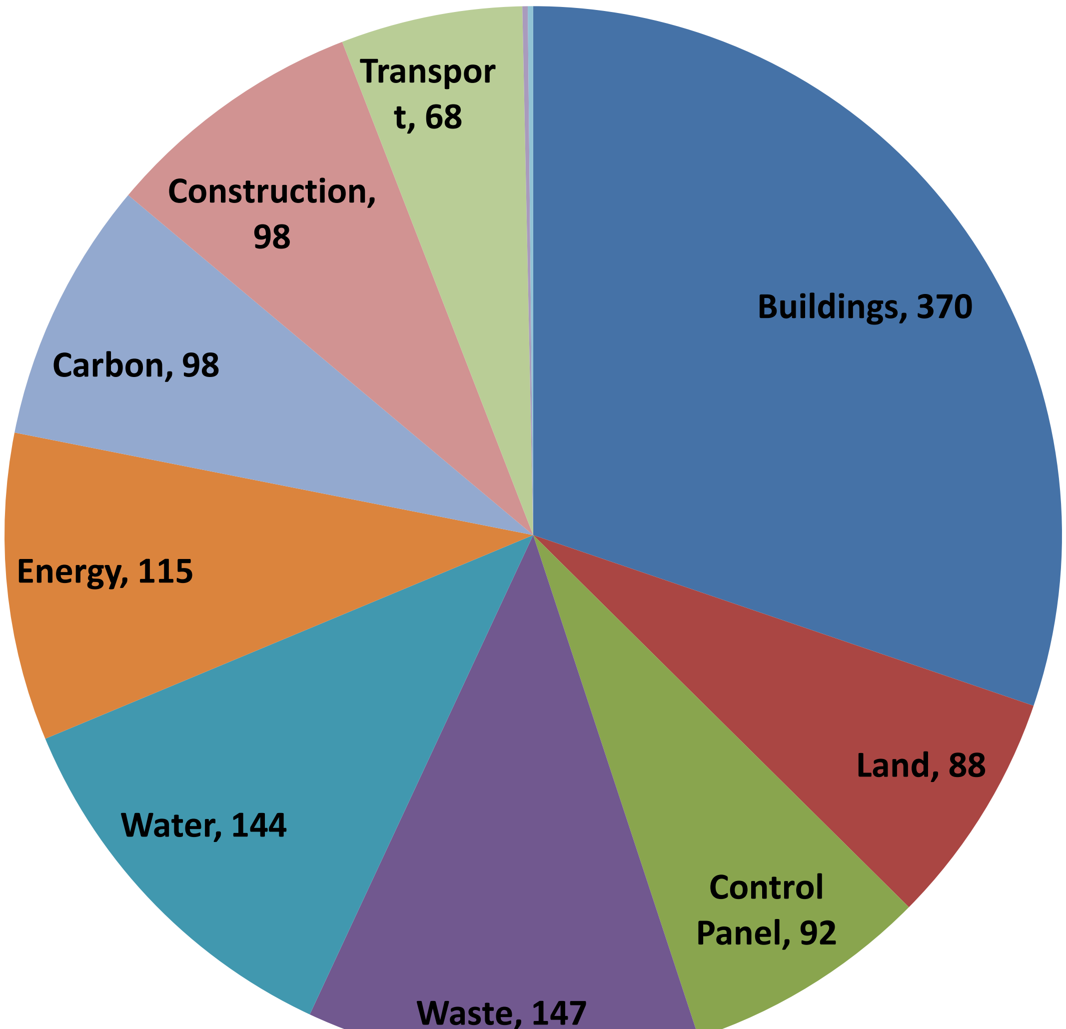
- Total Constants Found: 27,783
- Cells with Constants: 11.88%
- Average Constants in cells with constants: 3.32
- Maximum Constants Found: 9
  - Most common Constants
  - 0 occurred 12664 times
  - False occurred 4430 times
  - 1 occurred 4185 times
  - True occurred 1989 times
  - 0.99 occurred 1112 times
  - 100 occurred 565 times
  - 2 occurred 474 times
  - 1000000 occurred 338 times
  - 'ON' occurred 274 times
  - 3.28 occurred 272 times
  - 1000 occurred 265 times
  - 'OFF' occurred 198 times
  - 0.85 occurred 139 times
  - 0.9 occurred 113 times
  - 3 occurred 108 times

Common Sub Expressions

Most Common Sub Expressions:

- `([Control_Panel!$J$59])= True` appeared in 449 formulas
- `([Control_Panel!$L$59])= True` appeared in 392 formulas
  - These two relate to whether or not Waste Reduction strategies are enabled
- `3.28 ^ 2` appeared in 272 formulas
  - Conversion factor – guess units!
- `1 - ([Control_Panel!$Q$75])` appeared in 240 formulas
- `1 - ([Control_Panel!$R$75])` appeared in 240 formulas
  - These two capture % of journeys within developments not removed through design
- `([Control_Panel!$J$70])= True` appeared in 126 formulas
- `([Control_Panel!$L$70])= True` appeared in 126 formulas
  - Enabling of anaerobic digestion
- `([Control_Panel!$Q$78])= 1` appeared in 120 formulas
  - Does the modal split of transport add up to 100%?

IRM Per Capita Carbon calculation has 1224 inputs



Discipline Metrics

Discipline Model	Cell Counts	Inputs	% Inputs	Average Valency
Land Use (LU)	38	24	63%	3.24
Socio Economic (SE)	38	23	61%	1.87
Passenger Trans (PT)	210	180	86%	1.57
Pass Trans Coeff (PTCo)	140	99	71%	2.44
Energy Demands (ED)	477	371	78%	1.89
Logistics (Lo)	133	111	83%	1.33
Logistics Coeff (LoCo)	16	16	100%	2.75
Water (Wa)	111	111	100%	1.00
Energy Supply (ES)	34	33	97%	1.79
Energy Sup Coeff (ESCo)	12	12	100%	6.00
Convert Factors (CF)	2	2	100%	18.00
Out: Energy Dem (SSED)	185	12	6%	3.32
Out: Energy Sup (SSES)	244	48	20%	4.40
Out: Logistics (SSLo)	67	0	0%	3.99
Out: Pass Trans (SSPT)	366	0	0%	3.71
Out: Socio-Econ (SSSE)	14	0	0%	4.21
Out: Water (SSW)	264	75	28%	4.08
Project Outputs (Out)	6	0	0%	14.83

Discipline Coupling Matrix

Shows references from cells to their data
Sheet {Row} makes X references to data in Sheet {Col}
Cells in Sheet {Col} are used by sheet {Row} X times

references from\to	Buildings	Carbon_C	Carbon	Constructi	Control_P	Energy_C	Energy	Extraction	Land	Land_C	Materials_	Sum_Land	Sum_Reso	Transport_	Transport	Waste	Water	Waste_C	Water_C
Buildings	309	0	0	0	132	0	0	0	66	0	0	0	0	0	0	0	0	0	0
Carbon_C	0	57488	52724	0	292	533	0	0	0	2716	252	0	0	350	35	0	0	350	0
Carbon	0	0	5772	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction	0	0	0	2205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Control_Panel	0	0	0	0	640	0	0	0	66	0	0	4	28	0	0	0	0	0	0
Energy_C	0	0	0	0	288	12384	4720	0	0	1843	0	0	0	0	0	0	0	0	489
Energy	0	0	0	0	0	0	5219	0	0	0	0	0	0	0	0	0	0	0	0
Extraction	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0
Land	378	0	0	0	132	0	0	0	1596	0	0	0	0	0	0	0	0	0	0
Land_C	5151	0	0	0	133	0	0	0	860	37047	0	0	0	1587	0	0	0	0	0
Materials_C	0	0	0	4410	168	0	0	0	0	2910	7908	0	0	0	0	0	0	0	0
Sum_Land_Use	0	0	0	0	2	0	0	0	0	5	0	20	0	0	0	0	0	0	0
Sum_Resources	0	486	0	0	0	153	0	0	0	25	0	0	3020	84	84	0	0	126	171
Transport_C	0	0	0	0	1440	0	0	0	0	2328	0	0	0	25056	18816	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14789	0	0	0	0
Waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1067	0	0	0
Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8009	0	0
Waste_C	0	0	0	0	2640	0	0	0	0	1455	0	0	0	0	0	3792	0	12372	0
Water_C	0	0	0	0	514	4	0	0	0	4559	0	0	0	0	0	0	6372	0	13696

Discipline Coupling Matrix

Shows references from cells to their data
Sheet {Row} makes X references to data in Sheet {Col}
Cells in Sheet {Col} are used by sheet {Row} X times

references from\to	Buildings	Carbon_C	Carbon	Construct	Control_P	Energy_C	Energy	Extraction	Land	Land_C	Materials	Sum_Land	Sum_Resc	Transport	Transport	Waste	Water	Waste_C	Water_C
Buildings	309	0	0	0	132	0	0	0	66	0	0	0	0	0	0	0	0	0	0
Carbon_C	0	57488	52724	0	292	533	0	0	0	2716	252	0	0	350	35	0	0	350	0
Carbon	0	0	5772	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction	0	0	0	2205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Control_Panel	0	0	0	0	640	0	0	0	66	0	0	4	28	0	0	0	0	0	0
Energy_C	0	0	0	0	288	12384	4720	0	0	1843	0	0	0	0	0	0	0	0	489
Energy	0	0	0	0	0	0	5219	0	0	0	0	0	0	0	0	0	0	0	0
Extraction	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0
Land	378	0	0	0	132	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0
Land_C	5151	0	0	0	133	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1587	0	0	0	0	0
Materials_C	0	0	0	4410	168	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0
Sum_Land_Use	0	0	0	0	2	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0
Sum_Resources	0	486	0	0	0	133	0	0	0	25	0	0	3020	84	84	0	0	126	171
Transport_C	0	0	0	0	1440	0	0	0	0	2328	0	0	0	25056	18816	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14789	0	0	0	0
Waste	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1067	0	0	0
Water	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	8009	0	0
Waste_C	0	0	0	0	2640	0	0	0	0	1455	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3792	0	12372	0
Water_C	0	0	0	0	514	4	0	0	0	4559	0	0	0	0	0	0	6372	0	13696

Energy and Transport don't talk
So what about electric cars?

Subsequent improvement to IRM model resolved this.

V1 Discipline Coupling

	01LU	02SE	03PT	03PTCo	04ED	05Lo	05LoCo	07Water	08ES	08ESCo	CF	SSEDES	SS_Lo	SS_Wa	SS_C02
01LU	0	0	0	0	0	0	0	0	0	0	0	24	0	18	0
02SE	0	0	0	0	0	0	0	0	0	0	0	0	0	16	1
03PT	0	0	16	0	0	0	0	0	0	0	0	0	0	0	60
03PTCo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
04ED	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0
05Lo	0	0	0	0	0	16	0	0	0	0	0	0	31	0	45
05LoCo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	135
07Water	0	0	0	0	0	0	0	0	0	0	0	0	0	111	0
08ES	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0
08ESCo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87
CF	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0
SS_ED_ES	0	0	0	0	0	0	0	0	0	0	0	10	0	0	21
SS_Lo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48
SS_Water	0	0	0	0	0	0	0	0	0	0	0	0	0	353	7
SS_Carbon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1066

Focus on Energy Supply, Water & CO2

V2 Discipline Coupling

New Focus on Passenger Transport

	01LU	02SE	03PT	PTCo	04ED	05Lo	LoCo	Wa	08ES	ESCo	CF	SS_Lo	SS_PT	SS_SE	SS_ES	SS_W	SS_ED	Out
01LU	19	5	0	0	0	0	0	0	0	0	0	0	0	12	0	15	53	0
02SE	0	19	0	0	0	0	0	0	0	0	0	0	0	23	0	5	0	0
03PT	0	0	60	0	0	0	0	0	0	0	0	0	210	0	0	0	0	0
PTCo	0	0	0	81	0	0	0	0	0	0	0	0	180	0	0	0	0	0
04ED	0	0	0	0	424	0	0	0	0	0	0	0	0	0	0	0	53	0
05Lo	0	0	0	0	0	44	0	0	0	0	0	89	0	0	0	0	0	0
LoCo	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0
Wa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111	0	0
08ES	0	0	0	0	0	0	0	0	1	0	0	0	0	0	59	0	0	0
ESCo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0
CF	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	35	0	0
SS_Lo	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0	0	45	0
SS_PT	0	0	0	0	0	0	0	0	0	0	0	0	453	0	0	0	60	3
SS_SE	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	7	0	5
SS_ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	424	0	1	59
SS_W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	449	6	0
SS_ED	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	175	12
Out	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5

Higher Internal Complexity

New Focus on Energy Demand

V3 Discipline Coupling

	ROW referenced by COLUMN	Inputs								Calculation							Outputs			
		Land	Buildings	Carbon	Constructi	Energy	Transport	Waste	Water	Land_C	Materials_	Transport	Waste_C	Water_C	Energy_C	Carbon_C	Sum_Land	Sum_Reso	Outputs	Control_P
Inputs	Land	1596	66	0	0	0	0	0	0	860	0	0	0	0	0	0	0	0	0	66
	Buildings	378	309	0	0	0	0	0	0	5151	0	0	0	0	0	0	0	0	0	0
	Carbon	0	0	5772	0	0	0	0	0	0	0	0	0	0	0	52724	0	0	0	0
	Construction	0	0	0	2205	0	0	0	0	0	4410	0	0	0	0	0	0	0	0	0
	Energy	0	0	0	0	5219	0	0	0	0	0	0	0	0	4720	0	0	0	0	0
	Transport	0	0	0	0	4	14789	0	0	0	0	18816	0	0	5	35	0	84	0	0
	Waste	0	0	0	0	0	0	1067	0	0	0	0	3792	0	0	0	0	0	0	0
	Water	0	0	0	0	0	0	0	8009	0	0	0	0	6372	0	0	0	0	0	0
Calculation	Land_C	0	0	0	0	0	0	0	0	37047	2910	2328	1455	4559	1843	2716	5	25	0	0
	Materials_C	0	0	0	0	0	0	0	0	0	7908	0	0	0	0	252	0	0	0	0
	Transport_C	0	0	0	0	3	0	0	0	1587	0	25056	0	0	8	350	0	84	0	0
	Waste_C	0	0	0	0	0	0	0	0	0	0	0	12372	0	0	350	0	126	0	0
	Water_C	0	0	0	0	0	0	0	0	0	0	0	0	13696	489	0	0	171	0	0
	Energy_C	0	0	0	0	0	0	0	0	0	0	0	0	4	12384	533	0	153	0	0
	Carbon_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57488	0	486	0	0
Outputs	Sum_Land_Use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	2	4
	Sum_Resources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3020	3	28
	Outputs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Control_Panel	132	132	0	0	0	0	0	0	133	168	1440	2640	514	288	292	2	0	0	640

V3 Discipline Coupling

New Materials Focus

Electric Cars

Land/Buildings more detailed

Higher Coupling

New Control Panel

New Waste Focus

	ROW referenced by COLUMN	Inputs								Calculation							Outputs			
		Land	Buildings	Carbon	Constructi	Energy	Transport	Waste	Water	Land_C	Materials	Transport	Waste_C	Water_C	Energy_C	Carbon_C	Sum_Land	Sum_Resc	Outputs	Control_P
Inputs	Land	1596	66	0	0	0	0	0	0	860	0	0	0	0	0	0	0	0	0	66
	Buildings	378	309	0	0	0	0	0	0	5151	0	0	0	0	0	0	0	0	0	0
	Carbon	0	0	5772	0	0	0	0	0	0	0	0	0	0	0	52724	0	0	0	0
	Construction	0	0	0	2205	0	0	0	0	0	4410	0	0	0	0	0	0	0	0	0
	Energy	0	0	0	0	5219	0	0	0	0	0	0	0	0	4720	0	0	0	0	0
	Transport	0	0	0	0	4	14789	0	0	0	0	18816	0	0	5	35	0	84	0	0
	Waste	0	0	0	0	0	0	1067	0	0	0	0	3792	0	0	0	0	0	0	0
	Water	0	0	0	0	0	0	0	8009	0	0	0	0	6372	0	0	0	0	0	0
Calculation	Land_C	0	0	0	0	0	0	0	0	37047	2910	2328	1455	4559	1843	2716	5	25	0	0
	Materials_C	0	0	0	0	0	0	0	0	0	7908	0	0	0	0	252	0	0	0	0
	Transport_C	0	0	0	0	3	0	0	0	1587	0	25056	0	0	8	350	0	84	0	0
	Waste_C	0	0	0	0	0	0	0	0	0	0	0	12372	0	0	350	0	126	0	0
	Water_C	0	0	0	0	0	0	0	0	0	0	0	0	13696	489	0	0	171	0	0
	Energy_C	0	0	0	0	0	0	0	0	0	0	0	0	4	12384	533	0	153	0	0
	Carbon_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57488	0	486	0	0
Outputs	Sum_Land_Use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	2	4
	Sum_Resources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3020	3	28
	Outputs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Control_Panel	132	132	0	0	0	0	0	0	133	168	1440	2640	514	288	292	2	0	0	640

Discipline Stability

- **Afferent Couplings (Ca):** The number of other packages that depend upon classes within the package is an indicator of the **package's responsibility**.
- **Efferent Couplings (Ce):** The number of other packages that the classes in the package depend upon is an indicator of the **package's independence**.
- **Instability (I):** The ratio of efferent coupling (Ce) to total coupling (Ce + Ca) such that I = Ce / (Ce + Ca). This metric is an indicator of the **package's resilience to change**. The range for this metric is 0 to 1, with

  I=0 indicating a completely **stable** package and

  I=1 indicating a completely **instable** package.

Discipline Stability

	Afferent Coupling (Responsibility)	Efferent Coupling (Independence)	Instability
Land Use	4	0	0%
Socio Economic	2	1	33%
Passenger Trans	1	0	0%
Pass Trans Coeff	1	0	0%
Energy Demands	1	0	0%
Logistics	1	0	0%
Logistics Coeff	1	0	0%
Water	1	0	0%
Energy Supply	1	0	0%
Energy Sup Coeff	1	0	0%
Convert Factors	2	0	0%
Out: Energy Dem	2	6	75%
Out: Energy Sup	2	3	60%
Out: Logistics	1	3	75%
Out: Pass Trans	2	2	50%
Out: Socio-Econ	2	2	50%
Out: Water	1	5	83%
Project Outputs	0	4	100%

- **Afferent = # dependants**
  - +ve = Likely to break other disciplines
- **Efferent = # dependencies**
  - +ve = likely to be broken
- **Instability =**

$$\frac{\text{\# dependencies}}{(\text{\#dependants}+\text{\#dependencies})}$$

Sensitivity Analysis

- **Demonstrates which input variables an output indicator is most sensitive to changes in.**
- Indicates which variables have the most **scope for changing** the output variable.
- A **relative** metric between input variables.

- Run many designed experiments then compute sensitivities

PB Analysis

- Plackett – Burman Designs specify a series of experimental runs.
- They require a number of runs linear with respect to the number of parameters
- Only exist for certain sizes
- Do not take account of aliasing / confounding - the effect of interactions between parameters.

Plackett R.L and Burman J.P. The Design of optimum Multifactorial experiments. *Biometrika*, 1946, pp.305-325

Inputs

- Model
- Factors to Analyse
  - Cell identifier,
  - Friendly name
  - Low value
  - High value
- KPI’s to consider

Sensitivity Analysis

	Normalised Sensitivity for CO_2e Emissions Per Capita		
Variable	**Total**	**Non-Domestic Buildings**	**External Transport**
FuelType Petrol City Car	100	0	100
CO2 emissions from gas combustion	91	100	0
FuelType Electric Heavy Rail	78	0	78
District Heat Demand - Gas Boiler	71	73	0
District Heat Efficiency - Gas Boiler	71	73	0
Gas Network Efficiency	68	83	0
Gas Network Demand	62	78	0
Electricity Demand from CHP	57	68	0
CH4 emissions from biomass	47	52	0
Efficiency of Heat from biomass	46	55	0

Value

- Focus engineers upon decisions with most scope for impact
- Identify relative scope for impact of design decisions
- Identify impact of uncertainty in model assumptions

Conclusions

- Approach: use spreadsheet analytics to explore the conceptual model
- Shown the value of Spreadsheet Analytics!
  - Extraction and Analysis Methodology (EAM)*
  - Visualisation to show communication
  - Model metrics indicate complexity and focus
  - Discipline coupling shows interdisciplinary comm.
  - Sensitivity analysis aids optimisation tasks

* Liang , H. and Birch, D. (2011), "Extraction and Analysis Methodology for Supporting Complex Sustainable Design", Proceedings of the 18th International Conference on Engineering Design (ICED11).