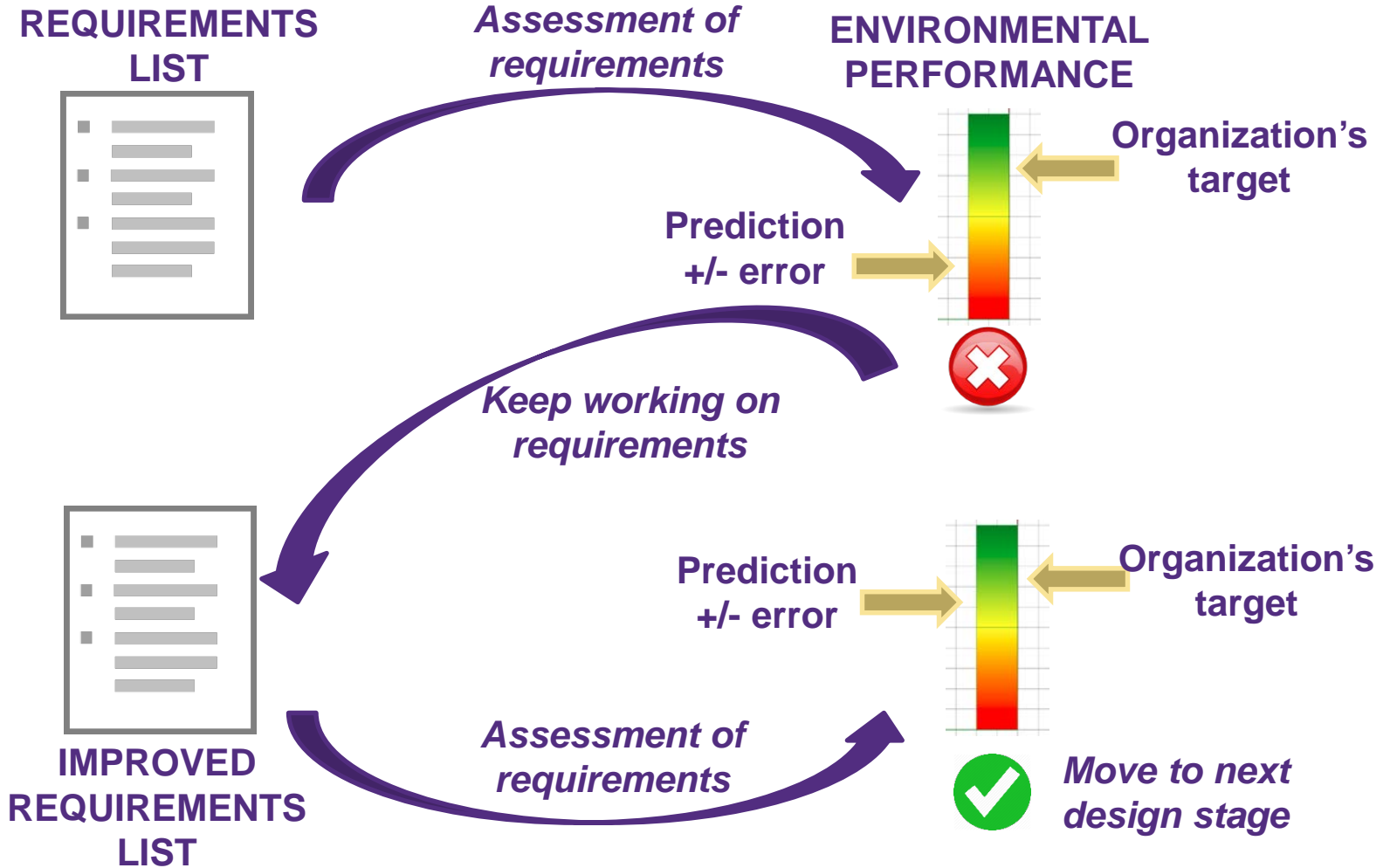
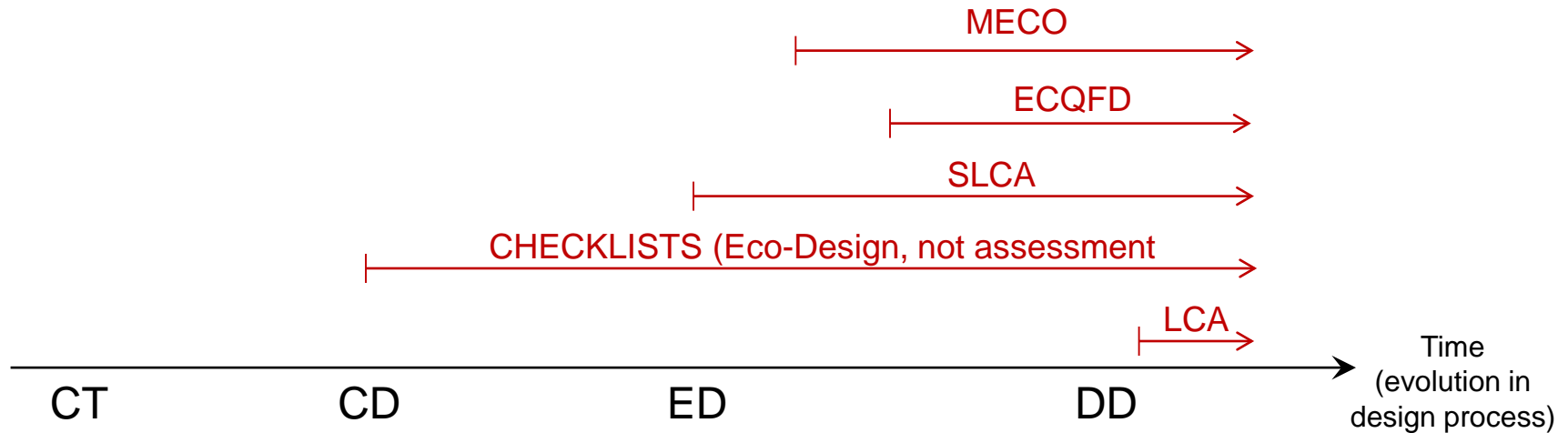

Using Design Requirements for Environmental Assessment of Products: A Historical Based Method

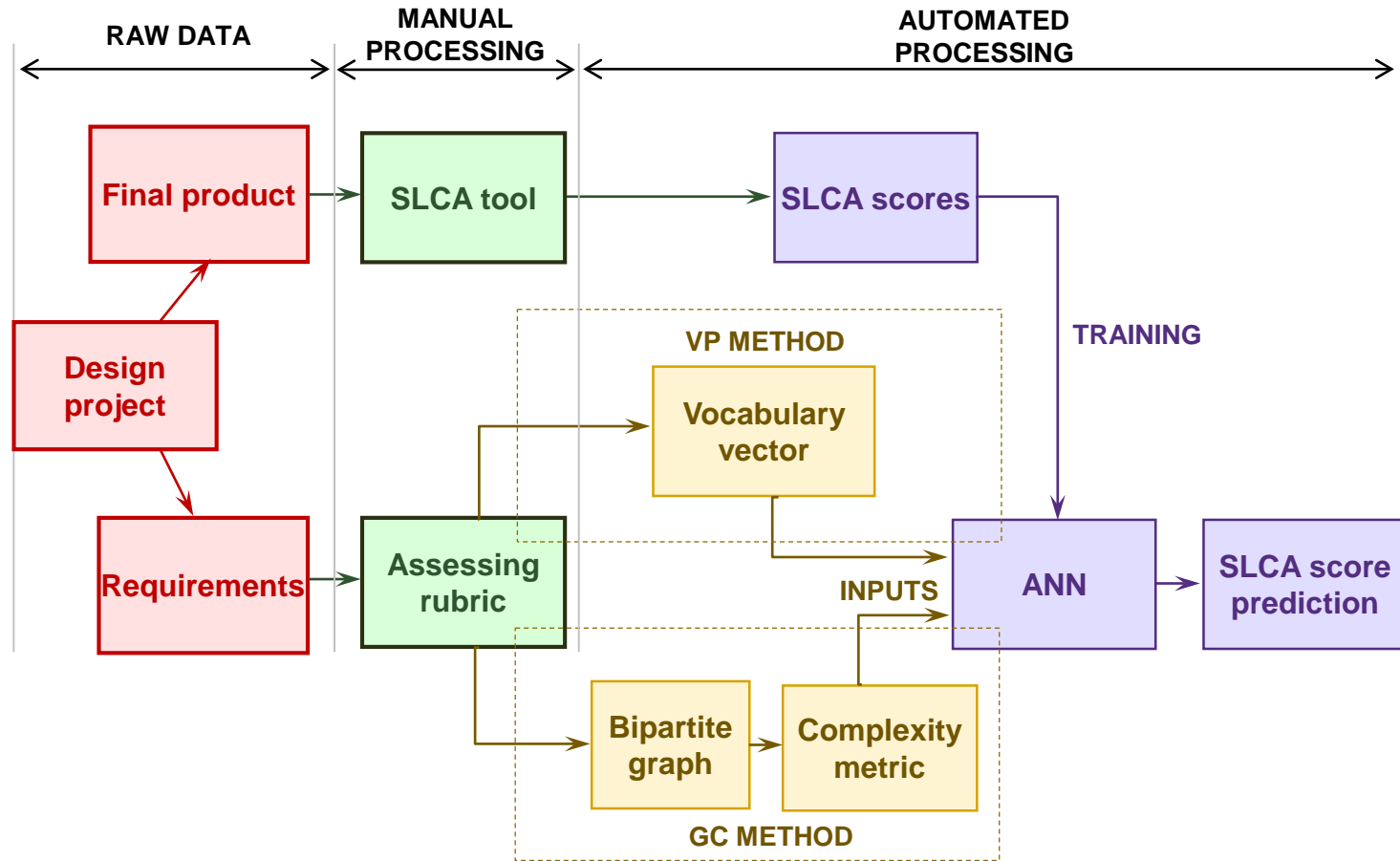
Darian Visotsky, Apurva Patel, Joshua D. Summers
Department of Mechanical Engineering
Clemson University
Clemson, SC 29634-0921



- Gap: existing environmental assessment tools require some degree of *embodiment* of the design

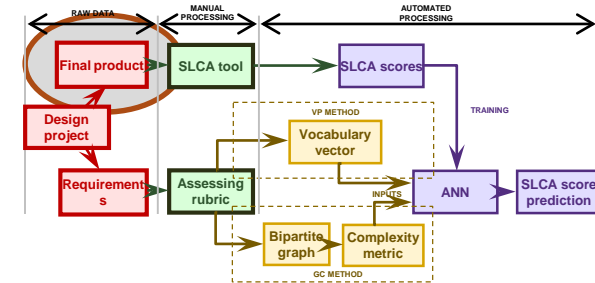


CT: Clarification of the task
CD: Conceptual design
ED: Embodiment design
DD: Detailed design

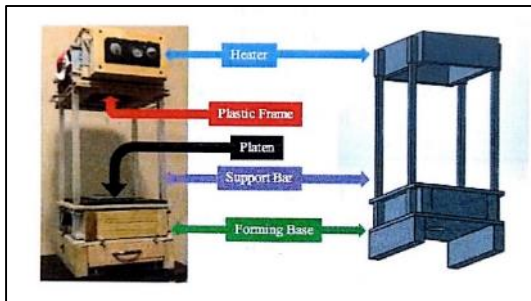


- Fifteen devices created by senior students for the course ME 4010 – Mechanical Engineering Design

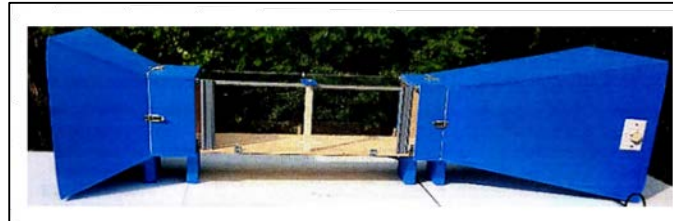
- 10 products from Spring 2015 (different devices)
- 5 products from Spring 2014 (all windtunnels)



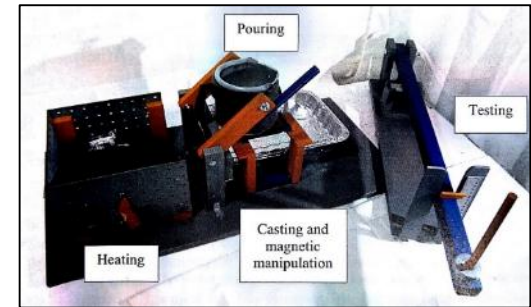
- NOTE: course did not involve lectures about environmental concerns



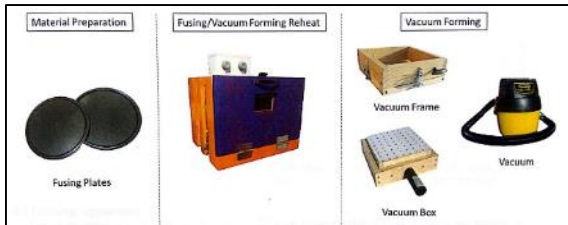
Project 1 – Vacuum forming system



Project 2 – Wind tunnel 1



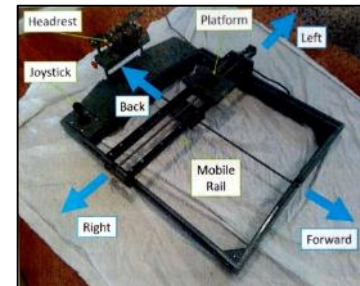
Project 3 – Wax casting with metallic particles



Project 4 – Plastic bag fusion and vacuum forming process



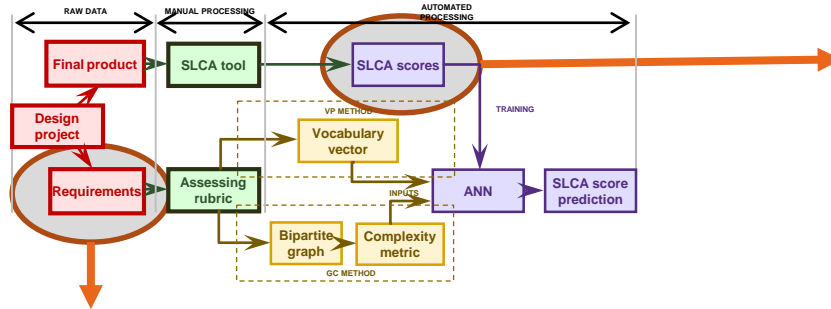
Project 5 – Wind tunnel 4



Project 6 – Virtual reality 1

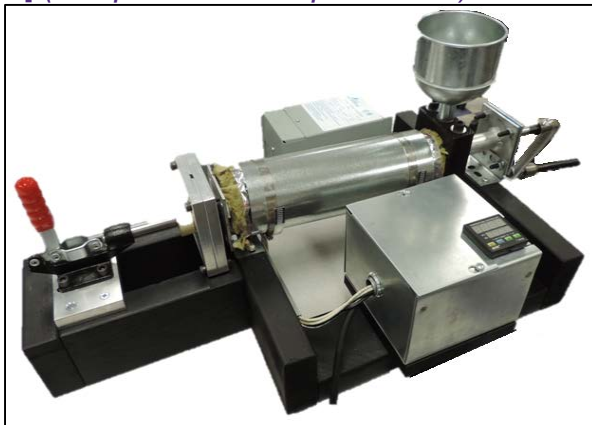


Project 7 – Vertical scissors press



- Project 12 – Injection molder demonstrator (requirements in report)

1. Clamping device must withstand mold pressures
 2. System should produce enough pressure to inject plastic
 3. Nozzle threads in piping (barrel) must withstand injection pressures
 4. Bearing design must withstand thrust
 5. Electrical energy must be transferred to thermal energy
 6. Thermal energy must melt the working material
- [...] (sample of 6/51 requirements)



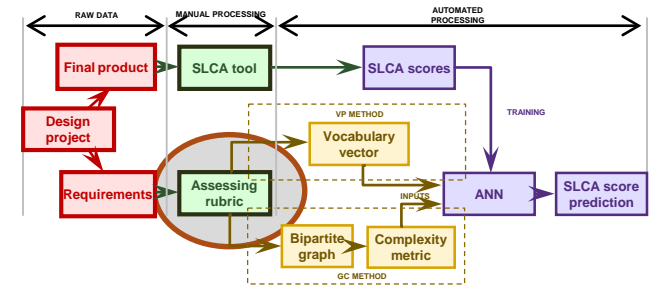
Project	SLCA scores
1- Vacuum forming system	70
2- Wind tunnel 1	76.25
3- Wax casting with metallic particles	70.5
4- Plastic bag fusion and vacuum forming process	69
5- Wind tunnel 4	80.75
6- Virtual reality 1	84.25
7- Vertical scissor press	77.75
8- Wind tunnel 3	88.75
9- Wind tunnel 2	79.25
10- Virtual reality 2	87.25
11- Laser engraver prototype	85.75
12- Injection molder demonstrator	69.25
13- Vacuum thermoformer design	71
14- Mechanical thermoforming	93.75
15- Metal stamping device	87.5

SLCA scores

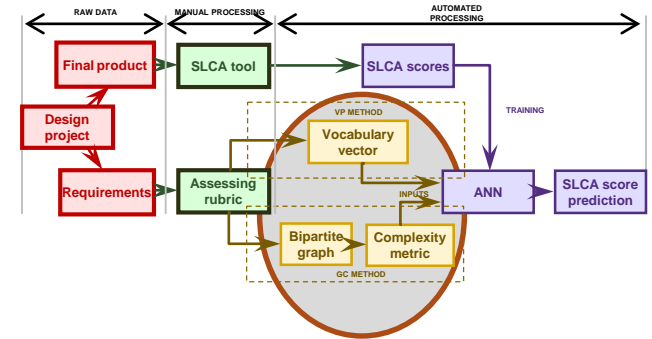
- Maximum score: 93.75
- Minimum score: 69
- Range: 24.75

- Results from assessment of two raters A and B of a testing list of requirements

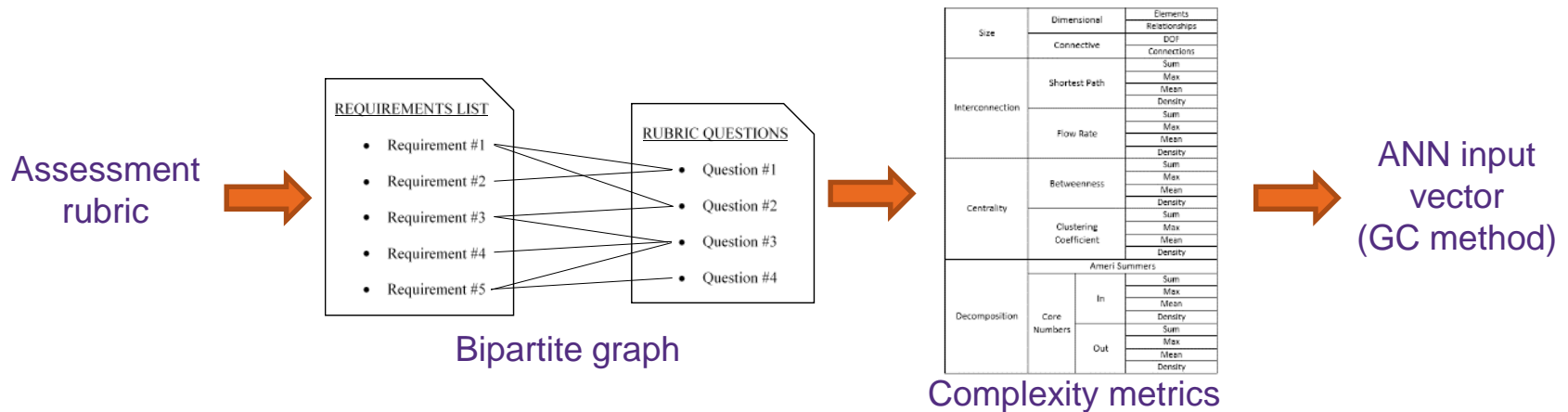
		Rubric questions	Number of agreements	Number of disagreements	Percent agreement	Cohen's Kappa
1. MATERIAL	1.1. Identification	1.1.1. Specific material	25	2	92.6%	0.471
		1.1.2. Material class	25	2	92.6%	0.71
		1.1.3. Material family	27	0	100.0%	1
	1.2. Reference to a property?	1.2.1. Explicit	25	2	92.6%	0.471
		1.2.2. Implicit	24	3	88.9%	0.521
	1.3. Reference to performance?	1.3.1. Explicit	23	4	85.2%	0.26
		1.3.2. Implicit	27	0	100%	1
2. ENERGY	2.1. Energy form	2.1.1. Explicit	27	0	100%	1
		2.1.2. Implicit	24	3	88.9%	0.362
	2.2. Quantification	2.2.1. Value with energy/power units	26	1	96.3%	0.78
		2.2.2. Value with indirect reference to energy	26	1	96.3%	0.649
		2.2.3. Qualitative	26	1	96.3%	0.836
	2.3. Energy performance	2.3.1. Consumption	27	0	100%	1
		2.3.2. Production	25	2	92.6%	0.471
		2.3.3. Efficiency	27	0	100%	1
2.3.4. Transport		27	0	100%	1	



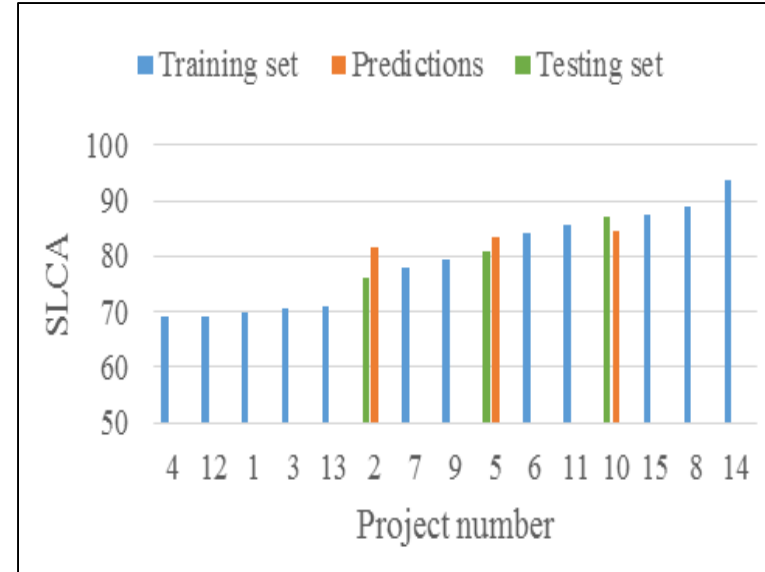
- ANN prediction models CEDAR lab
 - 189 Architectures (avoid “art”)
 - 100 Replications (avoid “chance”)
 - “Making Small Data Big”



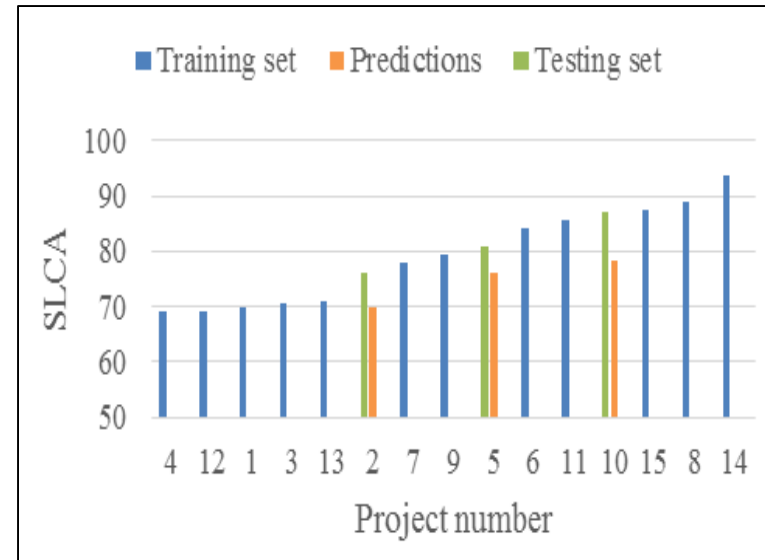
- Two methods to generate the input vectors:
 - Vocabulary processing (VP): the input vector is directly the output from the rubric
 - Graph complexity connectivity (GC): a bipartite graph is generated; 29 complexity metrics are calculated, which form the input vector



Trial 8	Test Projects			VP method
	2- Wind tunnel A	5- Wind tunnel 4	10- Augmented reality 2	
SLCA Target	76.25	80.75	87.25	Target ranking: P2 < P5 < P10
SLCA Predict.	81.48	83.36	84.64	Prediction ranking: P2 < P5 < P10
Std. Dev.	13.93	43.99	14.04	Maximum St. Dev.: 43.99
Res. Error	5.23	2.61	2.61	Avg. Residual error: 3.48
Std. error	0.069	0.032	0.030	Avg. Standard error: 0.044
Norm. error	0.004	0.001	0.001	Avg. Normalized error: 0.002



Trial 8	Test Projects			GC method
	2- Wind tunnel A	5- Wind tunnel 4	10- Augmented reality 2	
SLCA Target	76.25	80.75	87.25	Target ranking: P2 < P5 < P10
SLCA Predict.	69.82	76.24	78.41	Prediction ranking: P2 < P5 < P10
Std. Dev.	25.67	27.97	32.19	Maximum St. Dev.: 32.19
Res. error	6.43	4.51	8.84	Avg. Residual error: 6.59
Std. error	0.084	0.056	0.101	Avg. Standard error: 0.081
Norm. error	0.008	0.003	0.011	Avg. Normalized error: 0.008



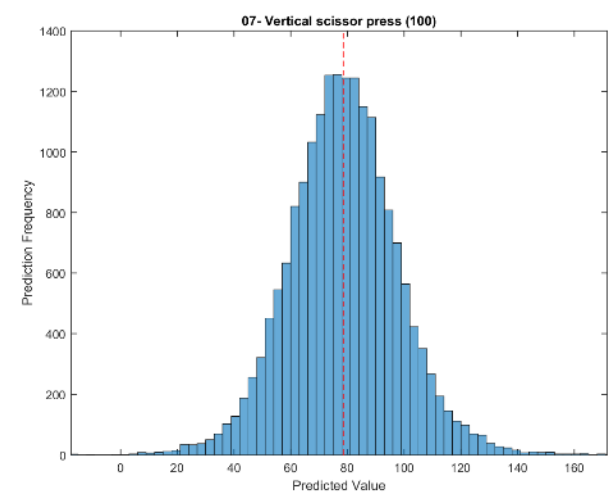
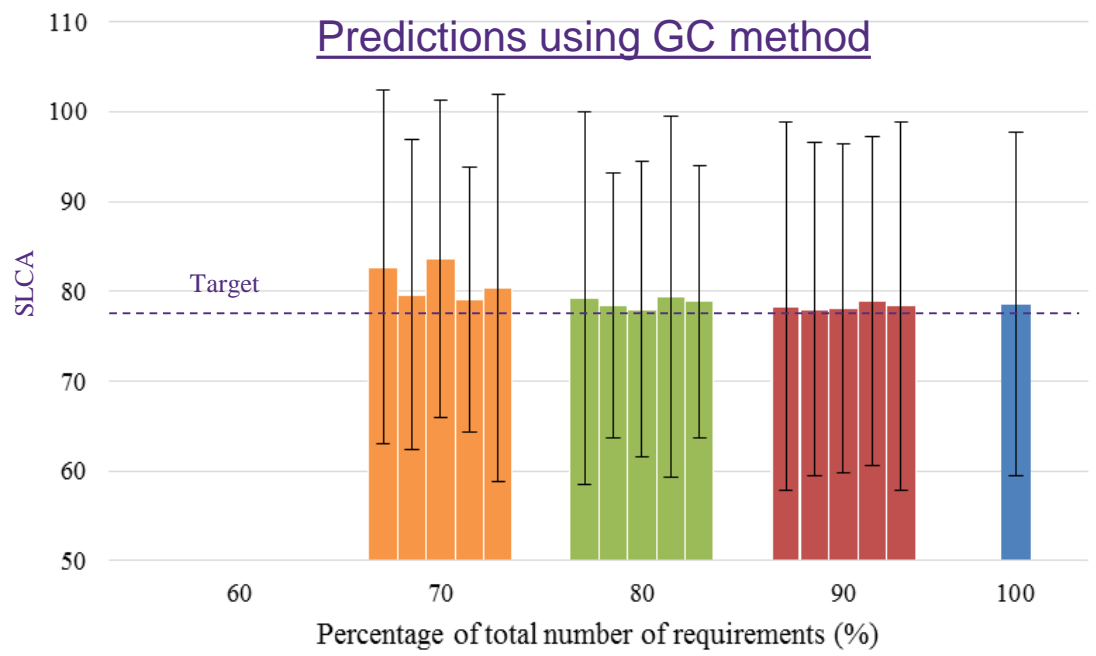
- Hypothesis:
 - Few requirements → poor representation of the problem
- Method:
 - Randomly remove requirements and analyze SLCA score prediction and standard deviation
 - Train ANN with remaining 14 products
 - Five groups of different sets of removed requirements

Product 7: Vertical scissor press

SLCA score = 77.75

Number of requirements: 46

- 10% of req.: 5 req.
- 20% of req.: 9 req.
- 30% of req.: 14 req.



- SLCA scores predictions were stable:
 - maximum average residual error was 12.21 (half of the scores range of 24.75)
- VP and GC methods led to comparable results
 - In general, GC resulted in less error, but an ANOVA test revealed that the difference was not significant
 - VP led to more accurate predictions of ranking of the scores predictions, which was verified through an ANOVA test
 - 3 of 6 trials, perfect ranking prediction
 - 2 of 6 trials, two orderings correct, one incorrect
 - 1 of 6 trials, ranking prediction completely flipped

