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IRC-ORAL-861

Xie, H.

2008-02-13

A version of this document is published in / Une version de ce document se trouve dans:
Workshop on Computational Tools and Technologies for Construction Practitioners (London, Ontario, February 13, 2008), February 13, 2008

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A Design Automation Tool for Construction

Computational Tools and Technologies for Construction Practitioners

Helen Xie

February 13, 2008

National Research Council Canada
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Agenda

- A design problem
- A design automation tool using constraint satisfaction approach
- An application case: elevator design
- Summary and future work

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A Design Problem

- A finite set of design **variables**
- **Domains** – a finite set of values for each design variable
- **Requirements**: a subset of design variables with assigned values
- A finite set of design **constraints** restricting combinations of variables
  - Constraint is an arbitrary relation over a set of variables
  - Can be defined as a set of compatible tuples or formula
- A design **solution** is a complete assignment of variables satisfying all the constraints

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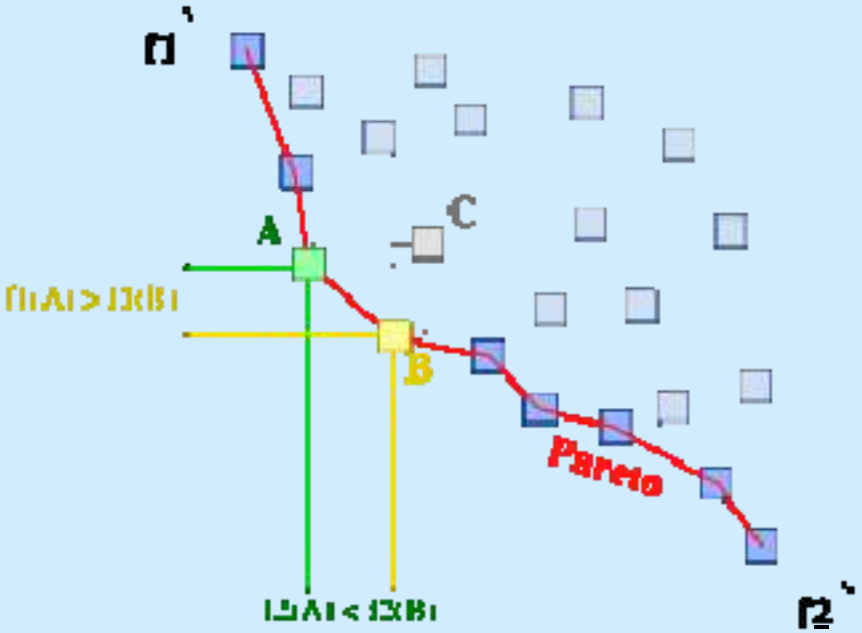
Design Optimization

- Multi-objectives – cost, reliability, maintainability
  - Conflict objectives
  - No single solution can be the best for all objectives
- Pareto frontier
- Preference
  - Seek an optimized solution for one objective, while setting a limit or a range for other objectives

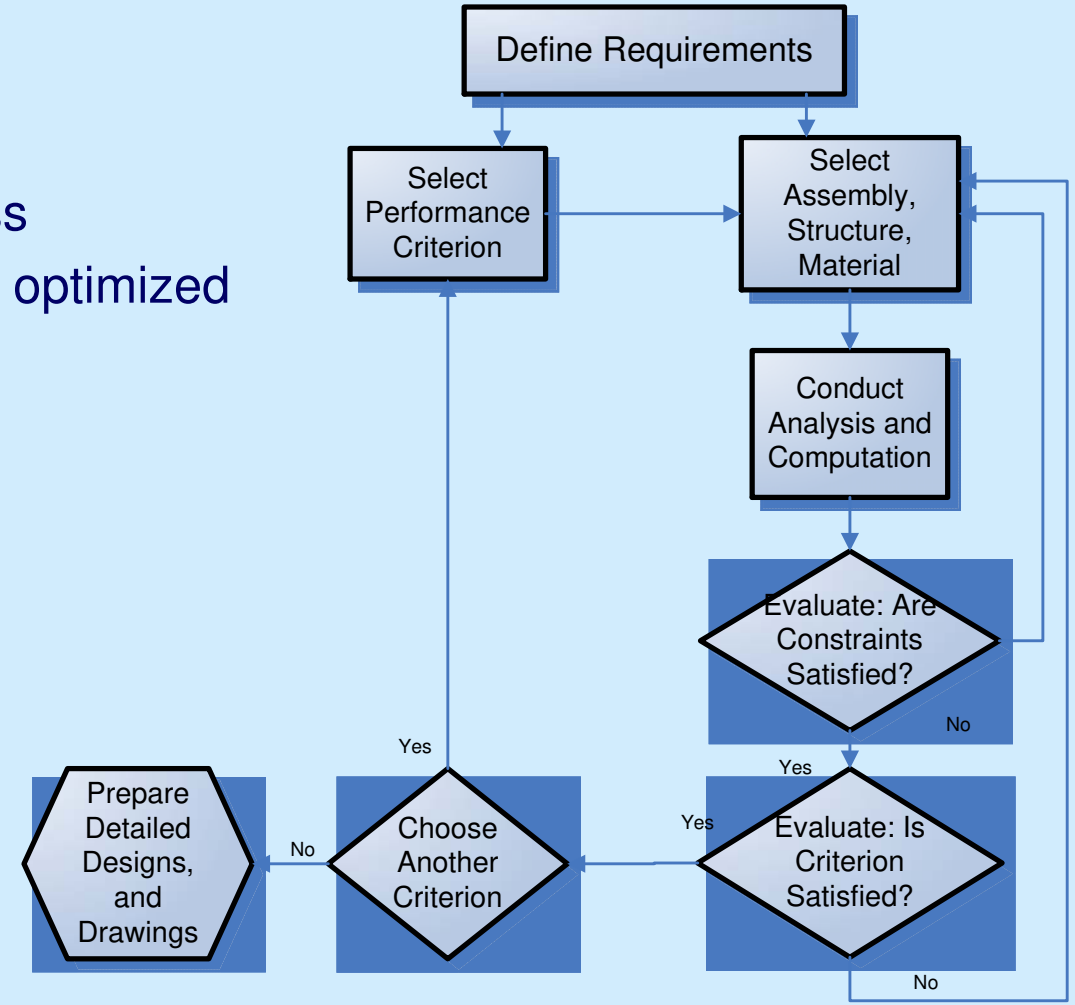


Pareto frontier

www.wikipedia.org

Approaches to solve a design problem (1/2)

- Trial and error
  - Repeated process
  - May miss out the optimized solution



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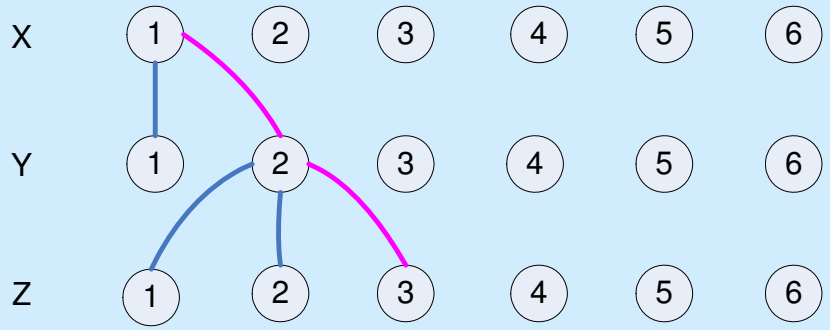
Approaches to solve a design problem (2/2)

- Constraint satisfaction approach
  - Systematic Search value combinations for all variables
  - Depth-first search
    - Assign a value to the variable
    - Propagate = make the problem locally consistent
    - Backtrack upon failure



Constraints:

X<Y

Z>X+1

Search Strategies

- Independent variable vs. dependent variable
  - Only search independent variables
- Variable ordering
  - Search a variable with a fewer number of values first
- Lazy updating
  - Only update affected variables
- Constraint consistency checking
  - Wait until all related variables are updated

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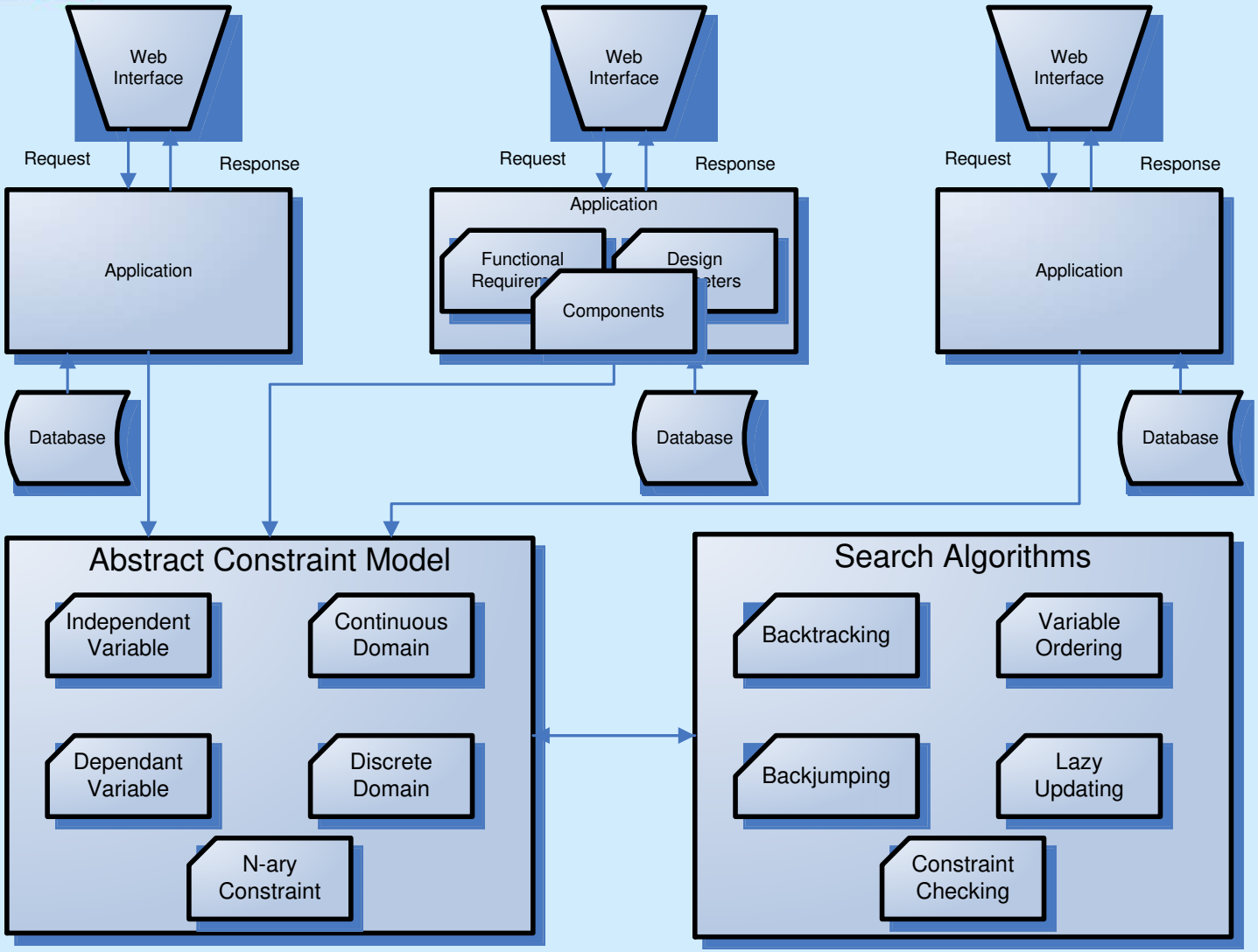
Software modules



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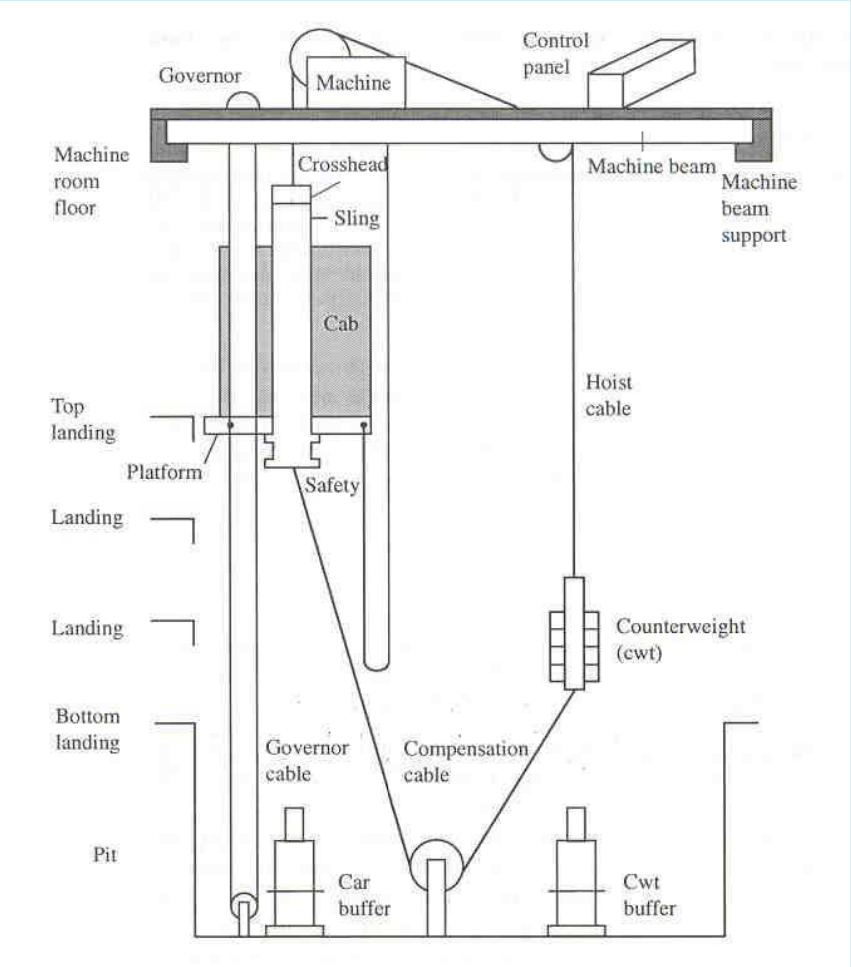
Benefits of Systematic Search

- Automate and speed up a design process
- Provide alternative solutions for evaluation and decision making support
- Possible to search all design space to find all solutions for preference handling and optimization

Application: elevator system design

- Variables (238)
- Functional requirements: capacity (load), speed,
- Building dimensions: opening, hoistway, pit, overhead
- Solution: motor, machine, machine beam, crosshead, sling, safety assembly, car assembly, platform, counterweight, cables



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Elevator system design

- Constraints (240)
  - Design tables
  - Formula
  - Equation

TABLE 7

Machine characteristics: MACHINE MODEL, MACHINE SUSPENDED LOAD MAXIMUM, MACHINE WEIGHT, MACHINE SHEAVE DIAMETER, MACHINE SHEAVE HEIGHT, MACHINE LEFT OFFSET, MACHINE RIGHT OFFSET

Machine model	Max sus-pended load (lb)	Weight (lbs)	Sheave diameter (in.)	Sheave height (in.)	Left offset (in.)	Right offset (in.)
18	11 500	1100	24	19	4.4375	9.4375
28	13 200	1700	30	26	8	8
38	20 000	2400	30	30	8	8
58	24 600	2750	32	33	14.75	14.75

MACHINE BEAM BENDING MOMENT LEFT MAXIMUM: $= R_{FL}D_1 + D_4(R_{FL} - W_{MB})$

MACHINE BEAM BENDING MOMENT RIGHT MAXIMUM: $= R_{FR}D_1 + D_4(R_{FR} - W_{MB})$

C-9. CAR RUNBY. The CAR RUNBY (S5.7) must be at least six inches. If it is not, increase the HOISTWAY PIT DEPTH (S3) by steps of one inch (**D9**). The CAR RUNBY (S5.7) must be at most 24 inches. If it is not, increase the CAR BUFFER BLOCKING HEIGHT (S5.7) by steps of one inch (**D4**).

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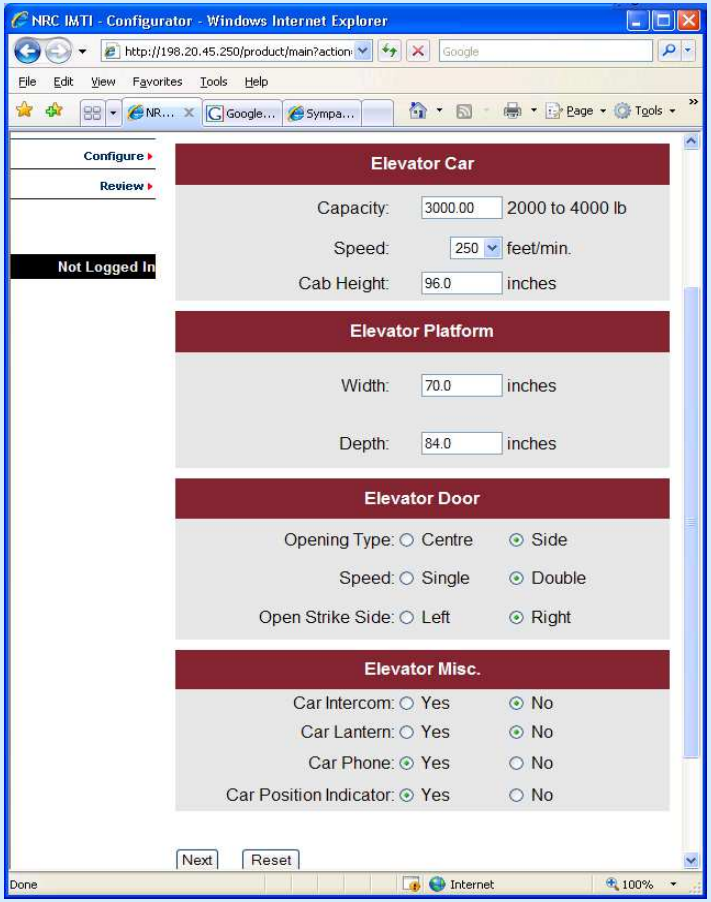
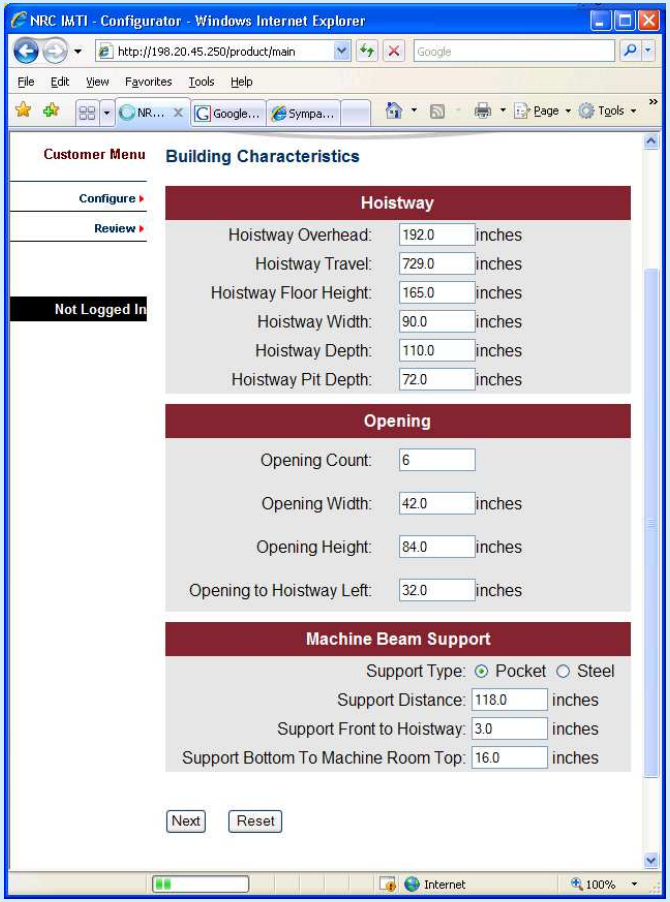
Design requirements





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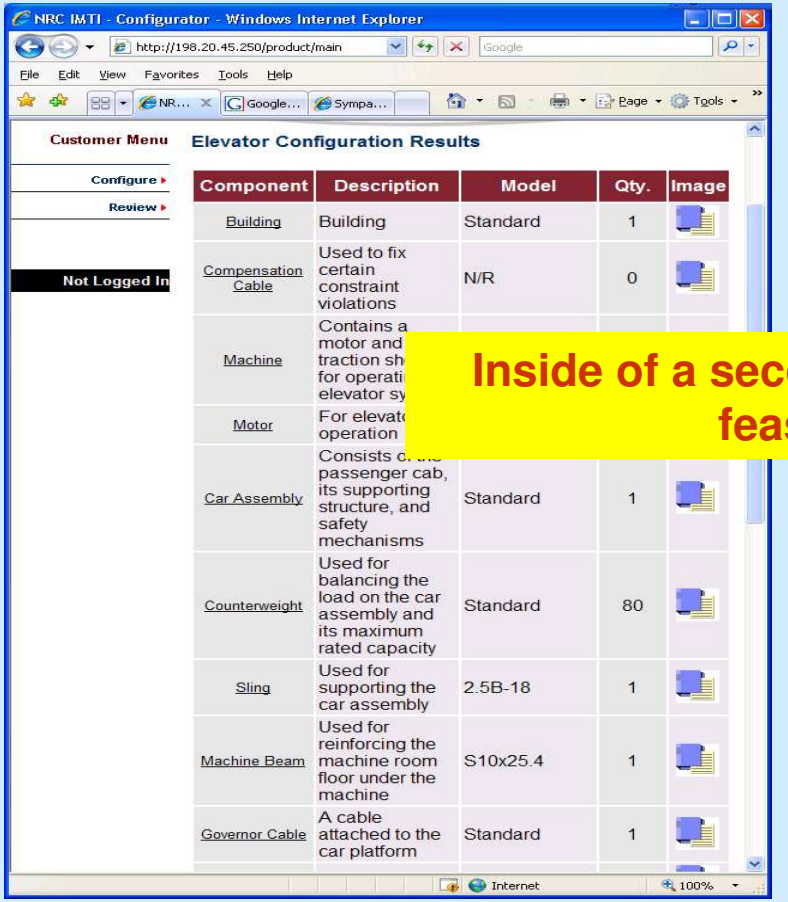
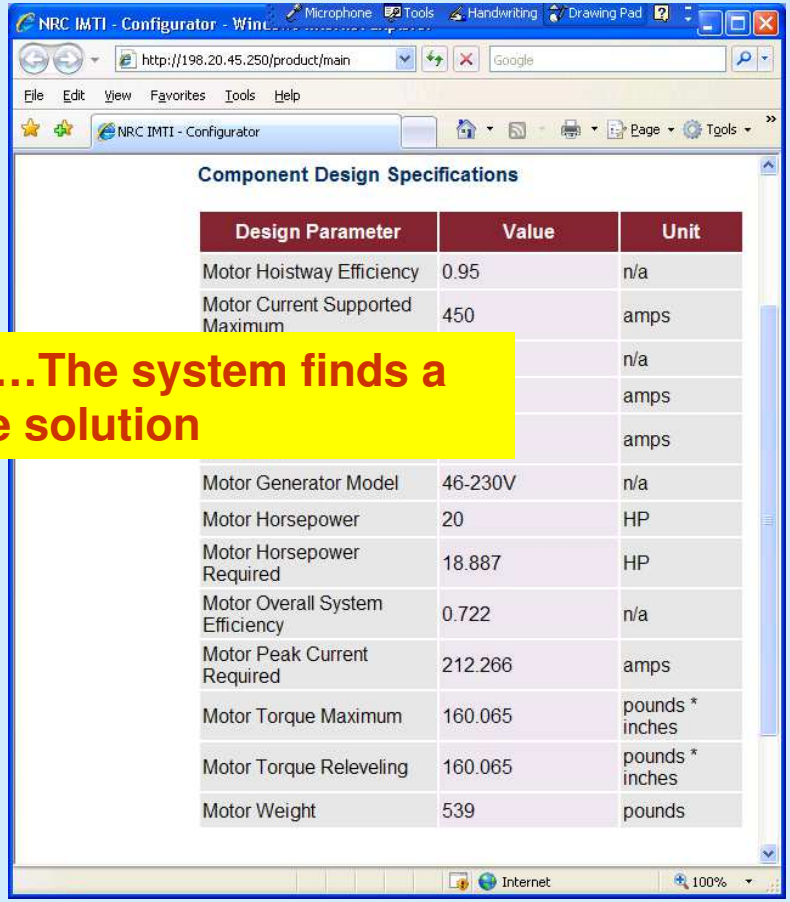
Design results



Inside of a second…The system finds a feasible solution



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Potential for another application

- Rigging system design
  - Load
  - Hub position
  - Rod angle
  - Cleat design

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Summary and future work

- Design automation tool
  - Design requirements
  - Generate multiple solutions for evaluation
  - Preference and optimization
- Feedback
  - Area of interests
- Applications in construction
  - IRC research results and experience
  - Design guide
  - Decision support tool

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