Design Theory SIG Meeting Paris 2015, MINES ParisTech

Design Science Research and Education

The important role of Design Theory

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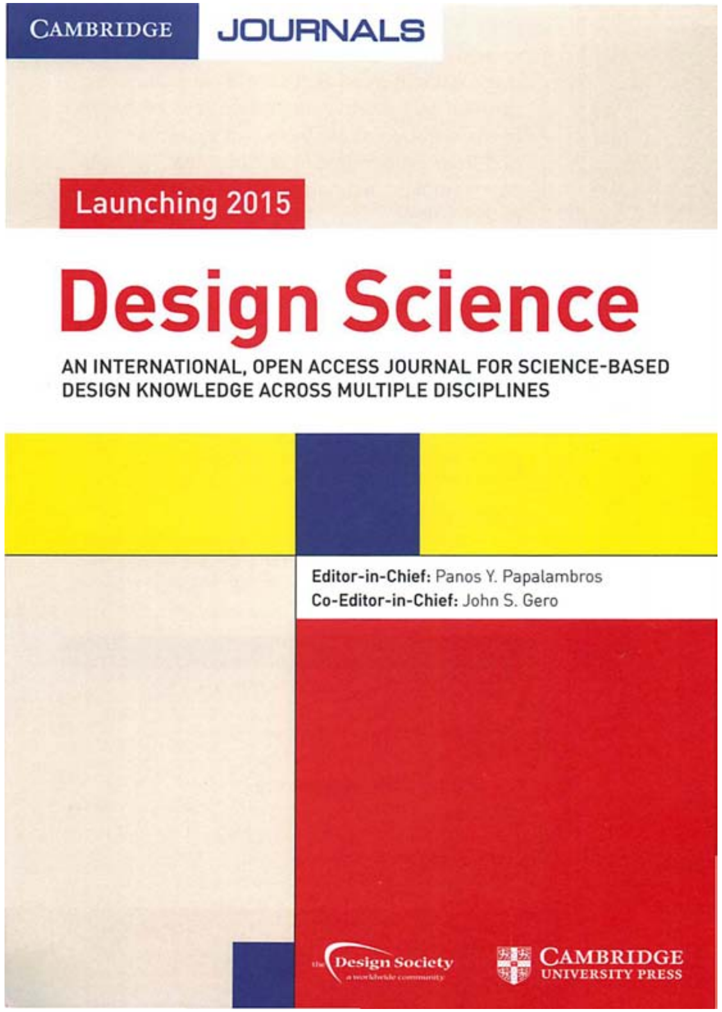
Greetings from …

and an invitation from …



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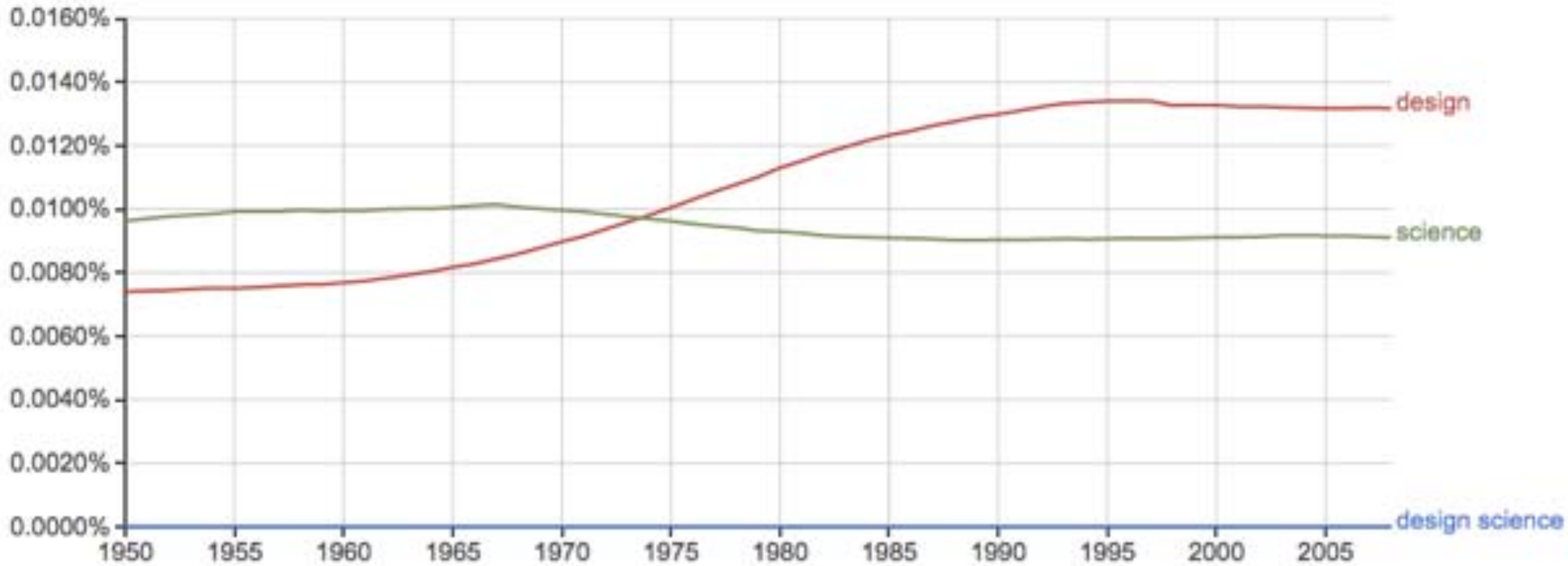
Talking Points

- Why design science?
- Why design theory?
- Why design (science) education as verification & validation of theory?

Design, science, design science

Use of *Science*, *Design*, *Design Science* over time according to Google Ngrams



Science is the intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment.

Etymology: from Old French, from Latin *scientia*, from *scire* 'know.'

Design (v.) from Latin *designare* "mark out, devise, choose, designate, appoint," from *de-* "out" + *signare* "to mark," from *signum* "a mark, sign". Originally in English with the meaning now attached to designate; many modern uses of design are metaphoric extensions.

Design (n.) from Middle French *desseign* "purpose, project, design," from Italian *disegno*, from *disegnare* "to mark out," from Latin *designare* "to mark out".

Design Science studies the creation of artifacts and their embedding in our physical, virtual, psychological, economic, and social environment —using the scientific method.

Etymology: … :-)

Why design theory?

Theory is a contemplative and rational type of abstract or generalizing thinking, or the results of such thinking.

A *scientific theory* is a well-substantiated explanation of some aspect of the natural world that is acquired through the scientific method and repeatedly tested and confirmed through observation and experimentation.

<u>Etymology</u>: Late Latin *theoria* (1592), from Greek Θεωρία.

From θεός (theós, "god") + ὁράω (horáō, "I see").

Why design education?

Education in its general sense is a form of learning in which the knowledge, skills, and habits of a group of people are transferred from one generation to the next through teaching, training, or research.

Etymology: From Latin *education*, from the verb *educare* which meant "bring up (children), train," which is related to *educere* "bring out, lead forth," from ex- "out" + ducere "to lead"

Apprenticeship is a system of training a new generation of practitioners of a structured competency in a basic set of skills.

Etymology: From Old French *aprentis*, from *apprendre* 'learn,' from Latin *apprehendere* 'apprehend.'

Training is the acquisition of knowledge, skills, and competencies as a result of the teaching of vocational or practical skills and knowledge that relate to specific useful competencies.

Etymology: From Old French *trahiner* (verb), from Latin *trahere* 'pull, draw.'

> Early noun senses were 'trailing part of a robe' and 'retinue'; the latter gave rise to 'line of traveling people or vehicles,' later 'a connected series of things.' The early verb sense 'cause (a plant) to grow in a desired shape' was the basis of the sense 'educate, instruct, teach.'

Pedagogy is the art, science, or profession of teaching

Etymology: From Greek παιδαγωγός (paidagōgós, "teacher, leader"), from παῖς (paîs, "child") + ἄγω (ágō, "I lead").

Originally, "slave who escorts boys to school and generally supervises them"

Design theory could, maybe should, be verified and validated in design… apprenticeship

education

pedagogy

training

Three Formal Design Education Experiences

Graduate: *Design Optimization*
Task: *Fine-tune design embodiment!*

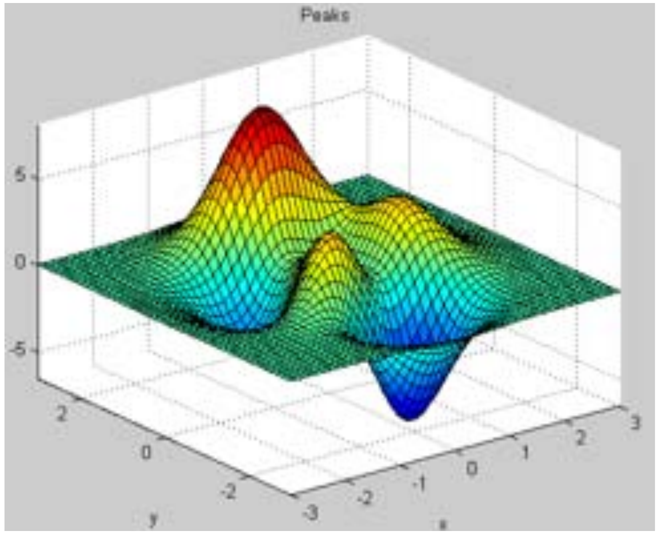
Senior Year: *Analytical Product Design*
Task: *Analyze what you can!*

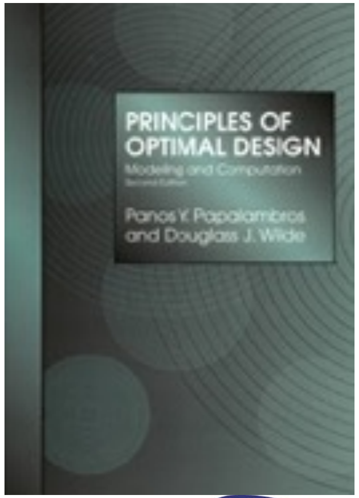
Sophomore Year: *Design & Manufacturing I*
Task: *Manage Complexity!*

Graduate: Design Optimization

Finetuning embodiment decisions

- Determine the best design from a large quantity of possibilities
- Express an objective and constraints in a mathematical function that is dependent on the design variables.
- The designer must have a mathematical understanding of the design objective and constraint functions.





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An Engineering Designer's view

Example: Optimal Design and Control of HEV Powertrains

Maximize:

$f(x)$ = mpg (combined fuel economy)

x = {engine, motor, battery, transmission, and controls}

Subject to:

g_1 = 0-60 mph time $\leq$ 12 seconds

g_2 = 40-60 mph (passing time) $\leq$ 5.3 seconds

g_3 = 0-85 mph time $\leq$ 23.4 seconds

g_4 = maximum acceleration $\geq$ 0.5 g

g_5 = maximum speed $\geq$ 85 mph

g_6 = 5 second distance $\geq$ 140 feet

g_7 = max grade at 55 mph $\geq$ 6.5%

g_8 = max grade at launch $\geq$ 30.0%

g_9 = Delta SOC for FUDS $\leq$ 0.5%

g_{10} = Delta SOC for FHDS $\leq$ 0.5%

Analyze what you can!

ANALYTICAL PRODUCT DESIGN

The design of artifacts is addressed from a multidisciplinary perspective that includes engineering, art, psychology, marketing, and economics.

Using a decision-making framework, emphasis is placed on understanding basic quantitative methods employed by the different disciplines for making design decisions, building mathematical models, and accounting for interdisciplinary interactions throughout the design development process.

Students work in teams to apply the methods on a design project from concept generation to prototyping and design verification.

Define chromosome

Initiate population

Visualize population

User selection

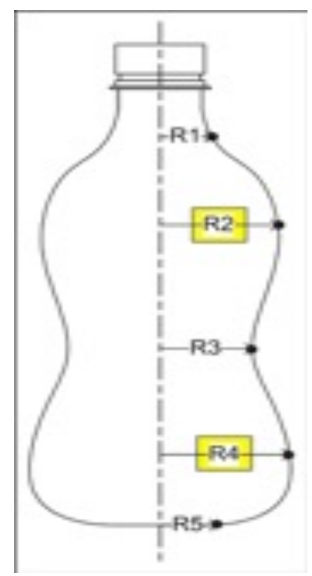
Best individual

New population

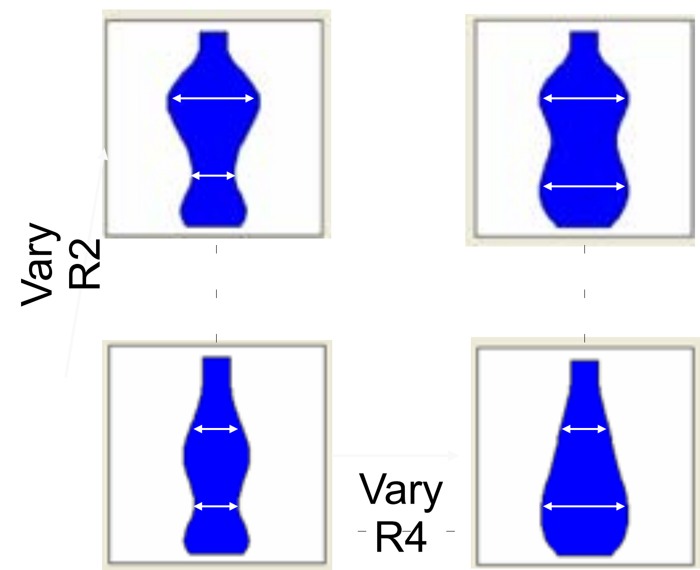
Crossover & Mutation

Bringing the humans in optimization

Interactive Genetic Algorithms (IGA)



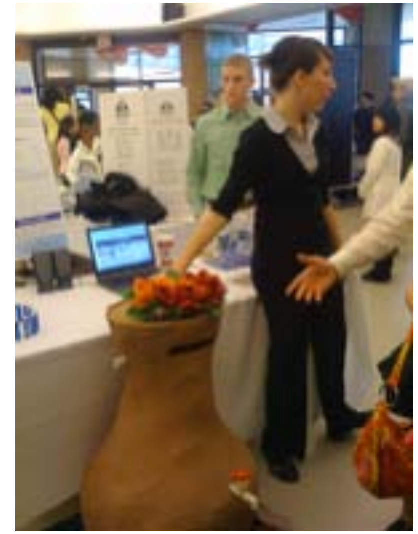
Potential bottle designs



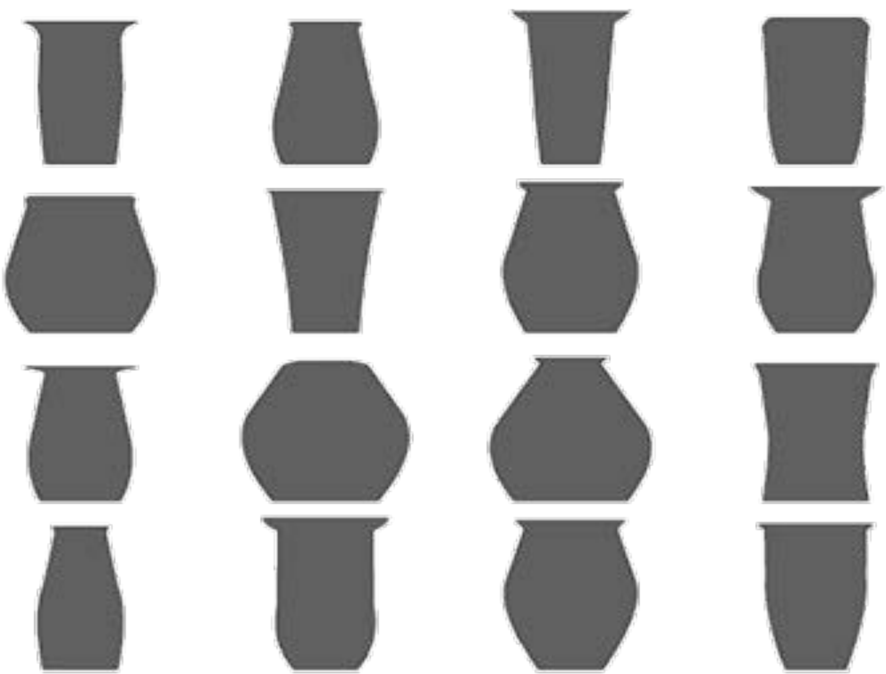
Jarod Kelly, PhD ME 2008; Research Scientist, Argonne National Laboratory

Rain Barrel Design

APD class project



Which of the following shape do you prefer as a rain barrel?



Tim Fries, Karen Hall, Kelly Johnson, Evan Sippel, and Deokkyun Yoon, "Let it Rain, Rain Barrels", Analytical Product Design Course Project, University of Michigan, Ann Arbor, 2008

Actual product family (on Amazon)

Algreen 81001 Cascata 65-Gallon Rain Water Collection and Storage System

by Algreen

(126 customer reviews)

Price: $199.99

"Very sturdy rain barrel that looks great, too!"

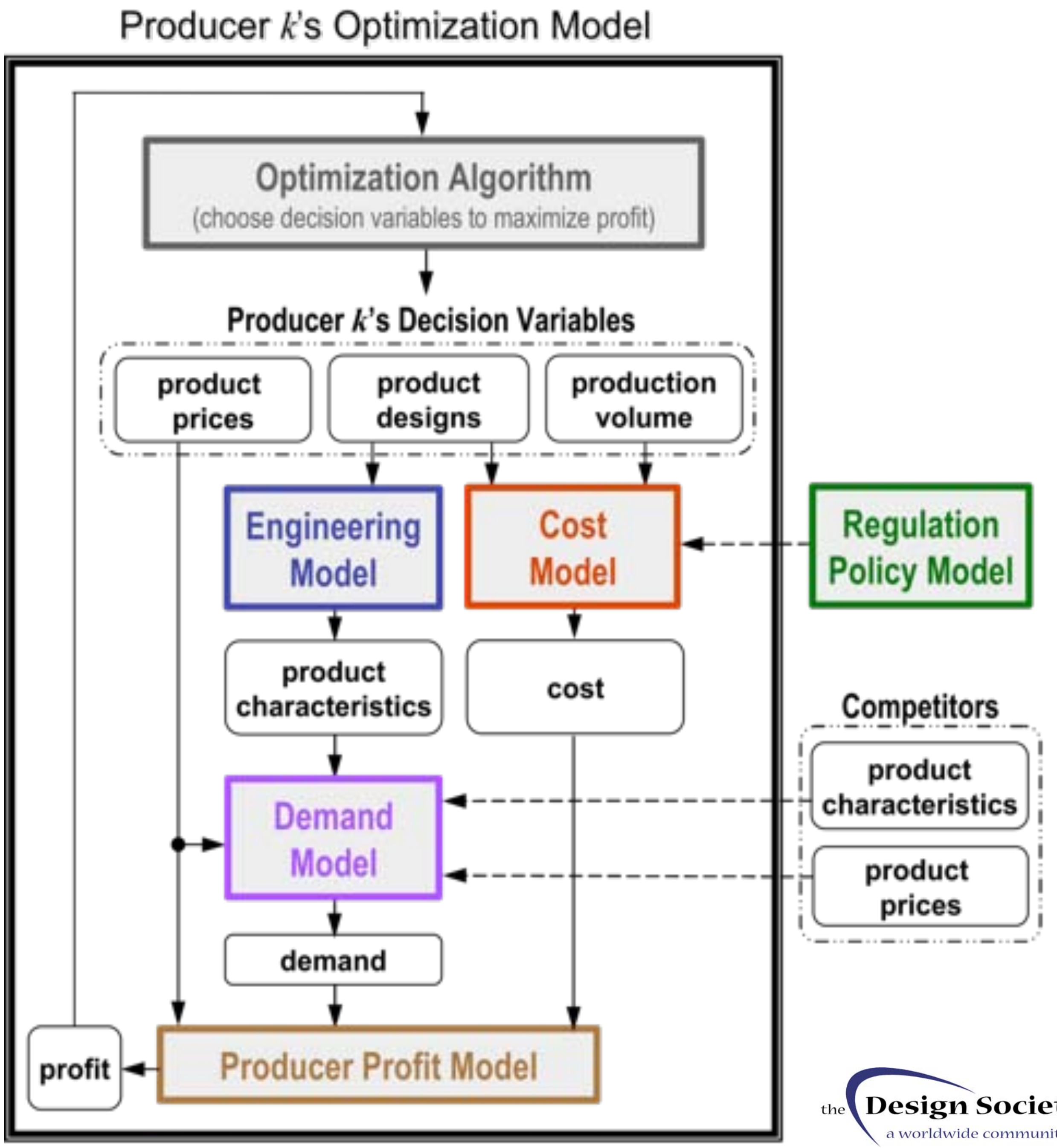
Wendy S. Johnson | 35 reviewers made a similar statement

"The design is really nice and the terra cotta look blends in nicely."

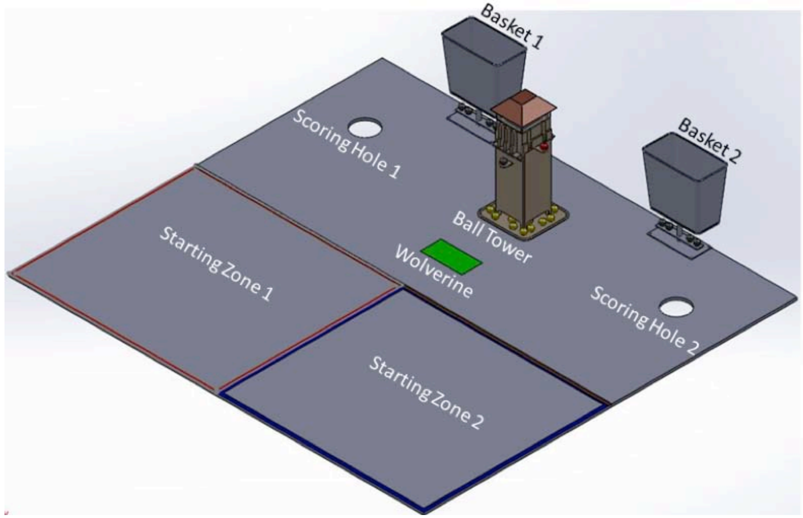
Judelake | 27 reviewers made a similar statement

A Producer's view

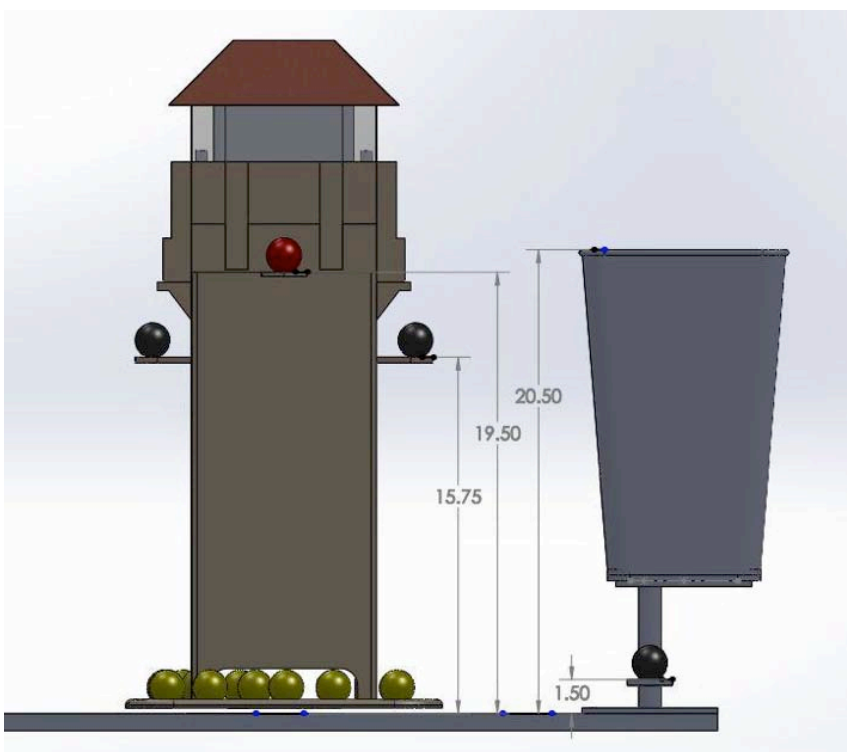
- Choose design, price, and production volume
- Determine cost, demand and profit
- Maximize profit

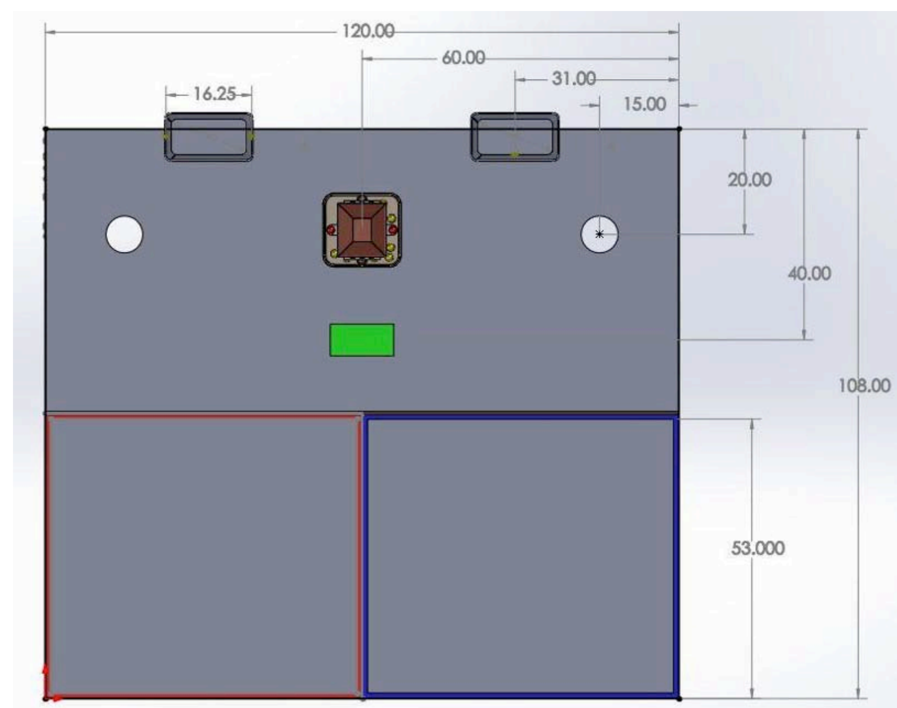


The MBall Game!

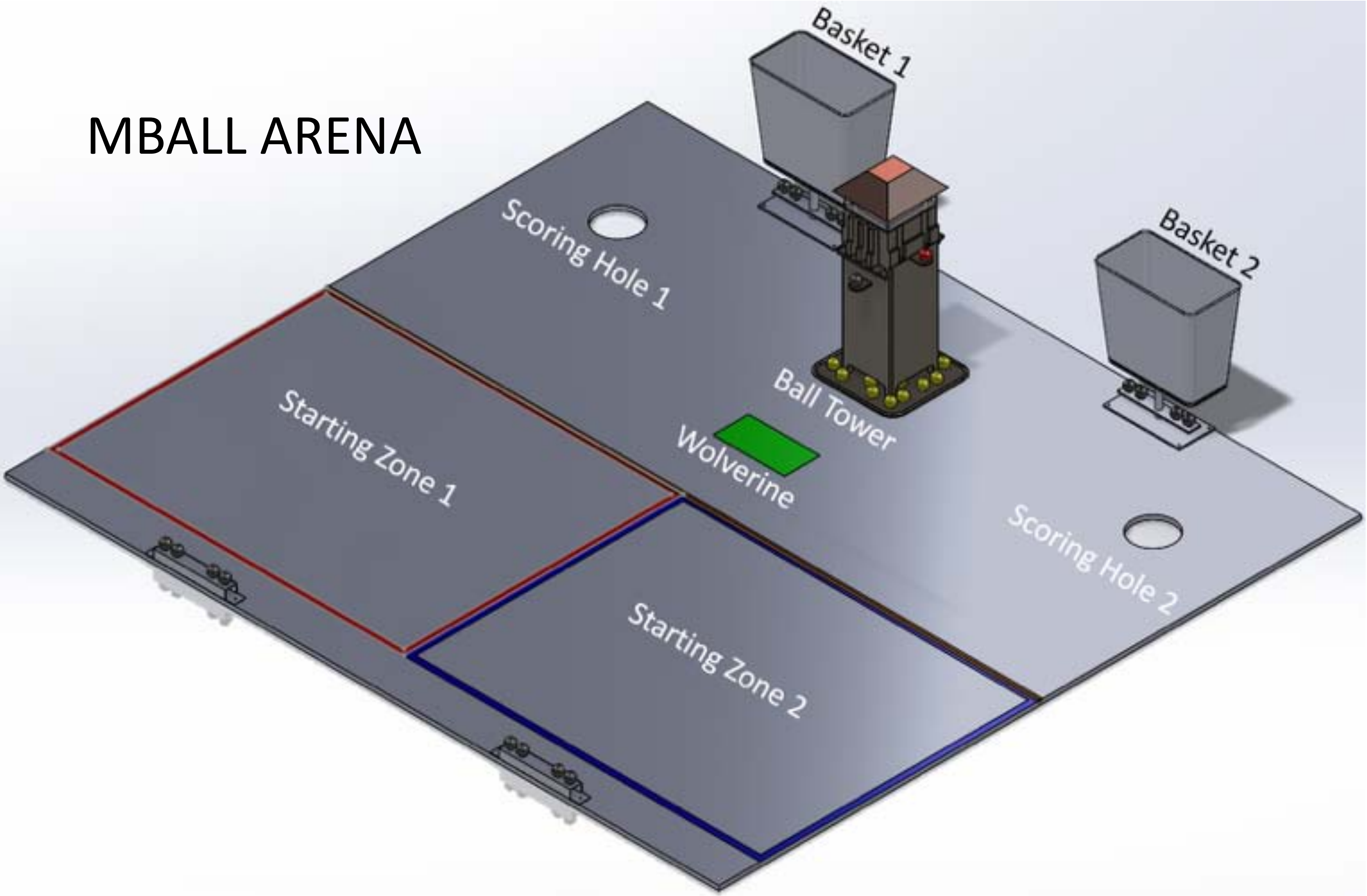


Term Project for
Design and Manufacturing I
(Sophomore Mechanical Engineering Course)

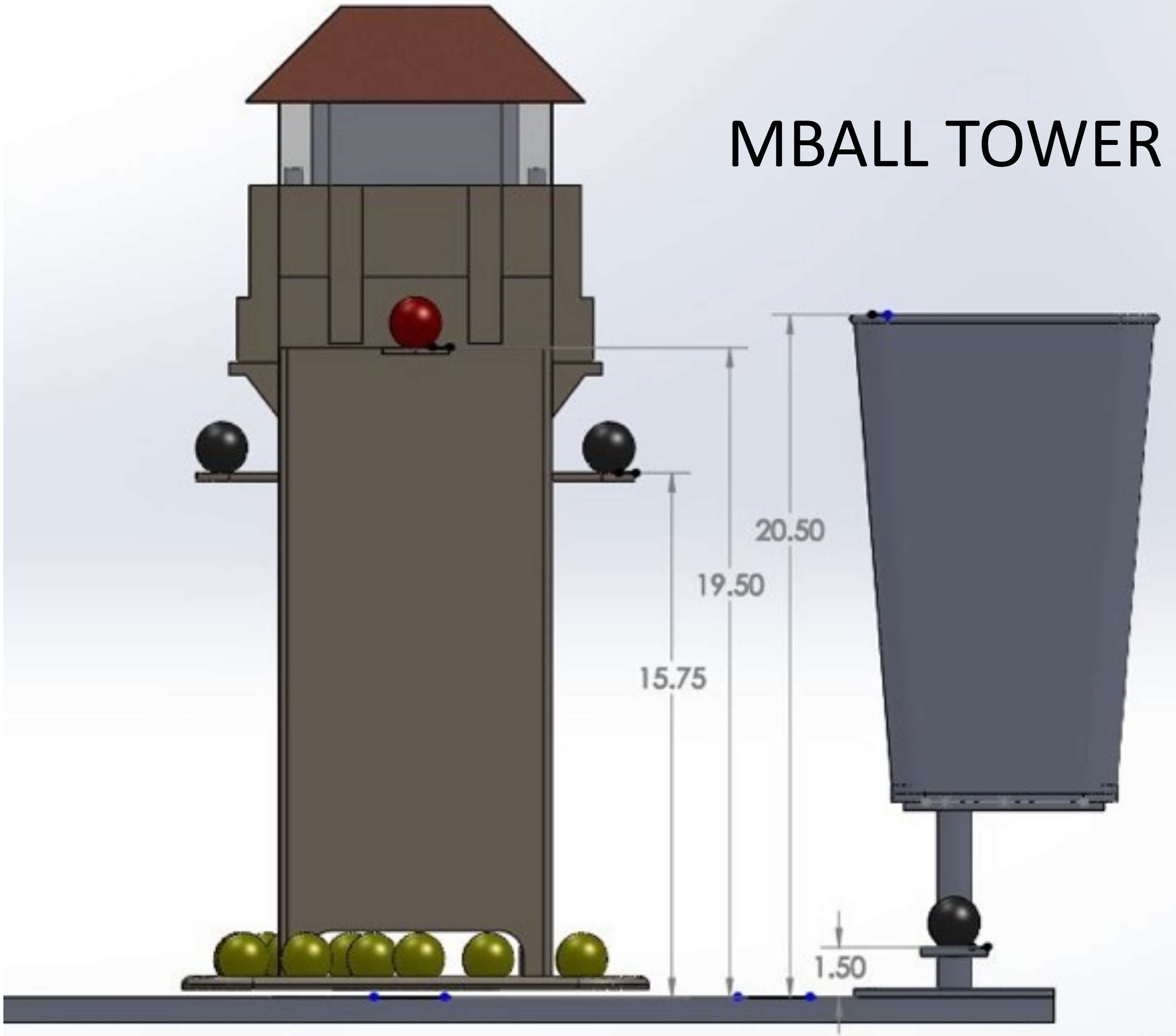




MBALL ARENA


Basket 1
Basket 2
Scoring Hole 1
Ball Tower
Wolverine
Starting Zone 1
Starting Zone 2
Scoring Hole 2

MBALL TOWER



Design Expo *MBall* Championship Game December 5, 2013

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UNIVERSITY OF MICHIGAN

Sophomore Year: Design & Manufacturing I

Manage Complexity!!

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An Executive's View

... I learnt how to understand a big problem, break it into small pieces, solve everyone of these pieces, and reintegrate them back into a system.... Previous attempts to introduce electric cars have failed because of a lack of systemic thinking.

Shai Agassi on the launch of Tesla Motors, as quoted by *The Economist* on March 1, 2008.

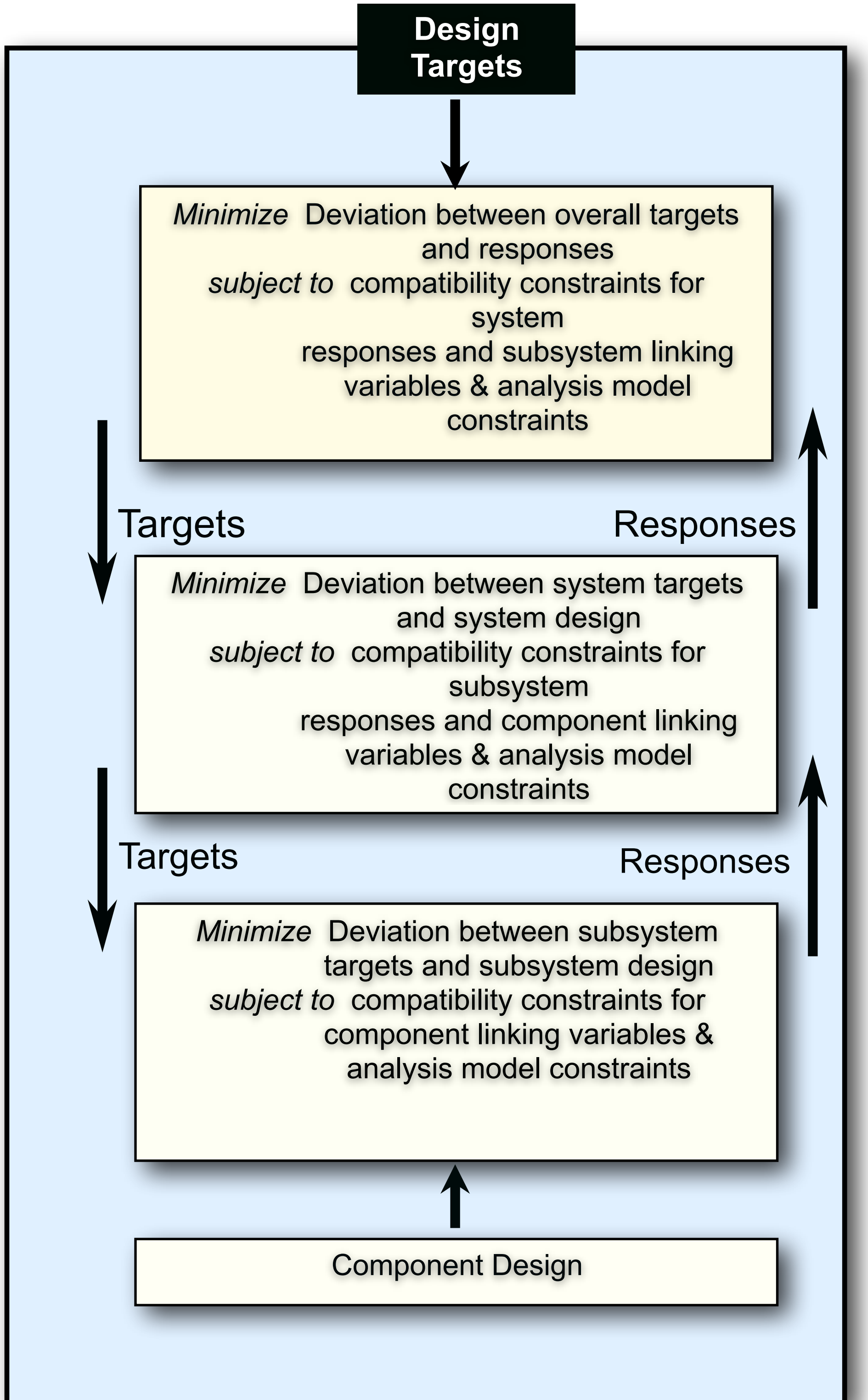
"*break it into small pieces*"

"*solve everyone of these pieces, and reintegrate them back into system*"

Partitioning

Coordination.

Decomposition Strategy



The Researcher's View

ANALYTICAL TARGET CASCADING

minimize $\quad \left\|\mathbf{R}_{ij}-\mathbf{R}_{ij}^{U}\right\|+\left\|\mathbf{y}_{ij}-\mathbf{y}_{ij}^{U}\right\|+\varepsilon_{ij}^{R}+\varepsilon_{ij}^{y}$

with respect to

$\mathbf{x}_{ij},\mathbf{y}_{ij},\mathbf{y}_{(i+1)k_1},\dots,\mathbf{y}_{(i+1)k_{n_{cij}}},\mathbf{R}_{(i+1)k_1},\dots,\mathbf{R}_{(i+1)k_{n_{cij}}},\varepsilon_{ij}^{R},\varepsilon_{ij}^{y}$

subject to

$$\sum_{k\in C_{ij}}\left\|\mathbf{R}_{(i+1)k}-\mathbf{R}_{(i+1)k}^{L}\right\|\le\varepsilon_{ij}^{R},\quad \sum_{k\in C_{ij}}\left\|\mathbf{y}_{(i+1)k}-\mathbf{y}_{(i+1)k}^{L}\right\|\le\varepsilon_{ij}^{y},$$

$$\mathbf{g}_{ij}(\mathbf{R}_{ij},\mathbf{x}_{ij},\mathbf{y}_{ij})\le\mathbf{0}\ ,\qquad \mathbf{h}_{ij}(\mathbf{R}_{ij},\mathbf{x}_{ij},\mathbf{y}_{ij})=\mathbf{0}$$

where $\quad \mathbf{R}_{ij}=\mathbf{r}_{ij}(\mathbf{R}_{(i+1)k_1},\dots,\mathbf{R}_{(i+1)k_{n_{cij}}},\mathbf{x}_{ij},\mathbf{y}_{ij})$

Activity: Generate the Squad's M-Ball Game Strategy

1 List primary functions: Ways that you can score or prevent the opponent from scoring.

2 Generate sub functions, e.g., on index cards, arrange the cards in rows and create a hierarchy (function tree).

3 Assign sub functions (can be more than one) to players.

4 Make a list of plays: Coordinate the players' roles.

This activity will be necessary to complete Milestone 1 and 2

Activity: Player

- State the player (team) design problem in 1-2 sentences. Then make a list of attributes that a good design solution should have.
- Make a matrix that maps attributes to characteristics. Identify how each characteristic will be measured.
- Classify the characteristics into objectives and requirements (constraints).
- Identify physical variables (quantities you have freedom to decide their values) and how each objective and constraint depends on these variables.

Activity: Generate the M-Ball Player Conceptual Design

1. List your player's primary functions: Use the Squads' assignment of subfunctions.
2. For your player, create a function tree.
3. Use brainstorming, mind-mapping, analogies and other ideation techniques to develop a conceptual design that performs the desired functions.
4. For your player's conceptual design, perform the attribute to design variable mapping.

Designs are artifacts.
Designing is about people.

Design science theories should support both.

Design education offers opportunities to check that.

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Thank you!