Archimedes might have said: *"Give me a good concept, and I will move the earth"*

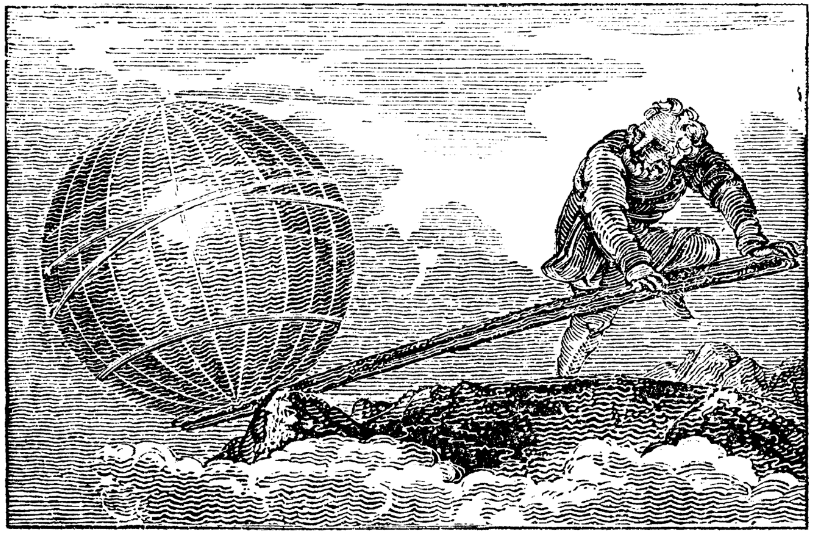
פרופ' יורם רייך, אוניברסיטת תל אביב

מושב 2.1 – תכן קונספטואלי וגיבוש חלופה נבחרת

ד"ר משה ויילר

Archimedes might have said:

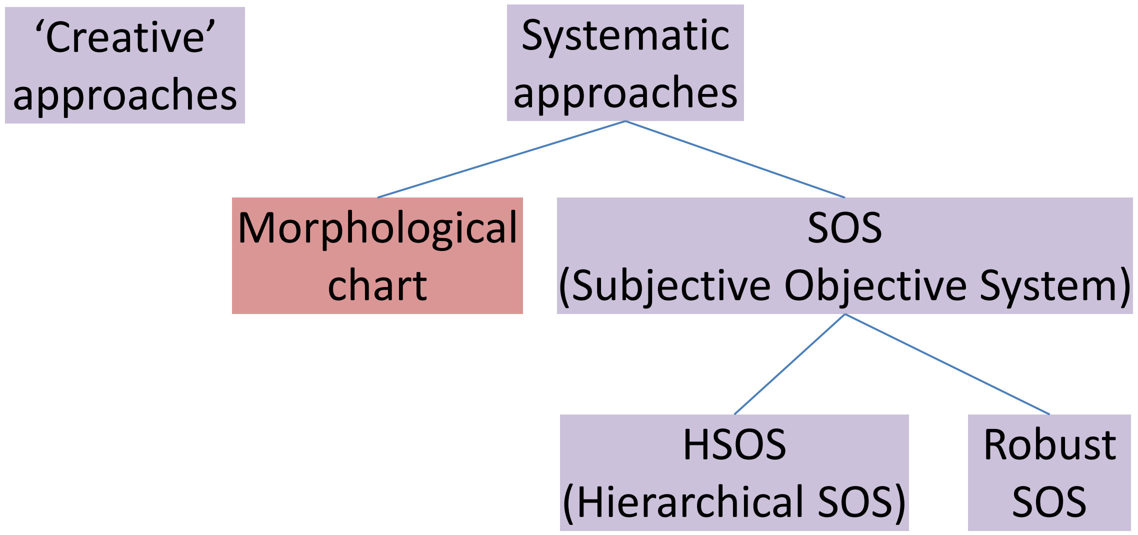
"Give me a good concept, and I will move the earth"



Prof. Yoram Reich
Tel Aviv University, Systems Engineering Research Initiative
TAU-SERI

Outline

1. What is a product concept & its importance?
2. How do we find it?



3. Summary

What is a product concept?

What is a product concept?

Product concept is an integrated collection of solution principles or technologies that provide the basis for solving a design problem

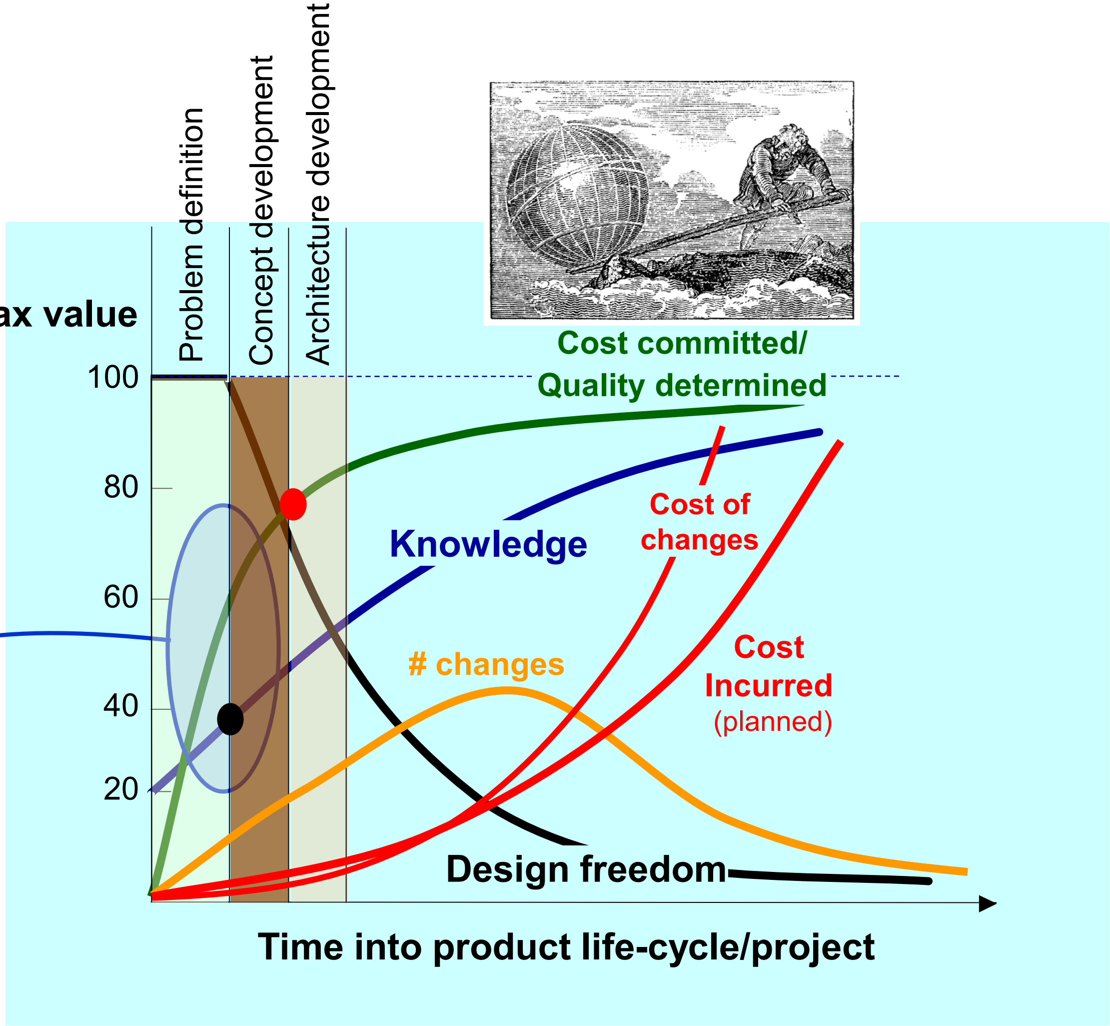
Commercial passenger aircraft concepts

Transport aircraft concepts

Fighter aircraft concepts

Why are concepts important?

The product development paradox (PDP)

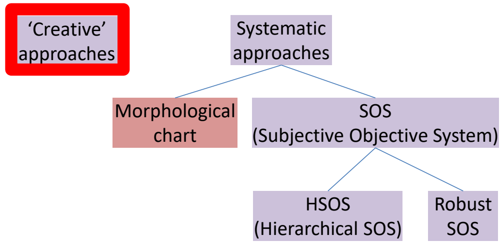


Knowledge is lacking when critical decisions are made → need **robust concepts**

Y. Reich, "Preventing Breakthroughs from Breakdowns," *Proceedings of the 9th Biennial ASME Conference on Engineering Systems Design and Analysis ESDA2008*, Haifa, Israel, 2008.

Where do concepts come from (1)?

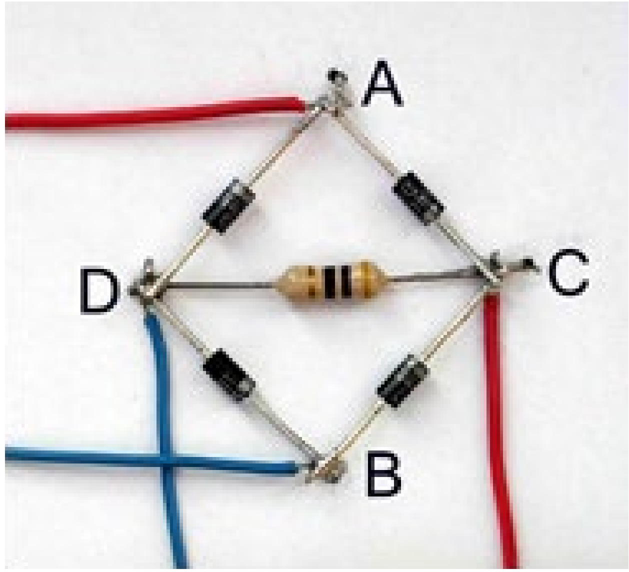
- Archimedes?

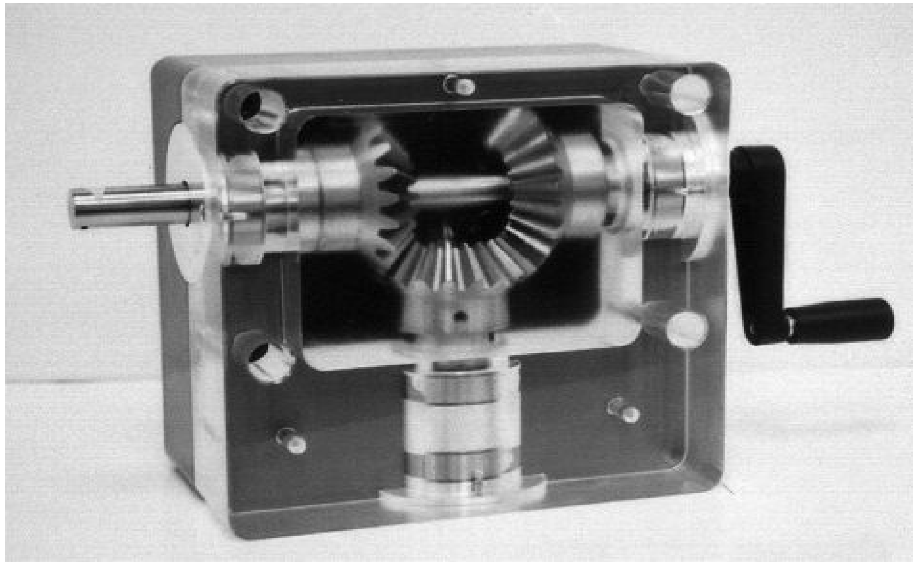


Where do concepts come from (2)?

- Problem:
  - Develop a screwdriver that turns the screw when I rotate the screwdriver in both directions

- Look into other technical disciplines





Courtesy Prof. Offer Shai

Shai, O., & Reich, Y. (2004). Infused design. II. Practice. *Research in Engineering Design*, *15*(2), 108-121.
Shai, O., Reich, Y., & Rubin, D. (2009). Creative conceptual design: extending the scope by infused design. *Computer-Aided Design*, *41*(3), 117-135.

Where do concepts come from (3)?

- Problem:
  - Reduce the drag of objects

- Look into nature - biomimicry

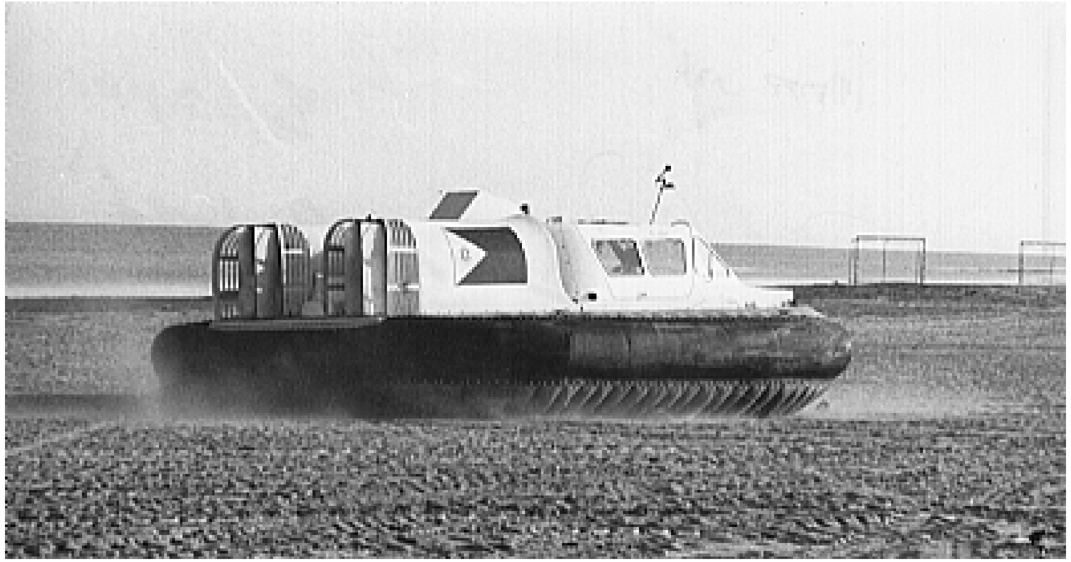
Cohen, Y. H., & Reich, Y. (2016). *Biomimetic design method for innovation and sustainability* (Vol. 10). Berlin, Germany: Springer.

Where do concepts come from (4)?

- Problem:
  - Develop an innovative ship concept

- Look into art, history, culture, poetry, etc.
- **Dancing ship** – seemingly unrelated concepts

hydrofoil



hovercraft

C-K theory, concept blending

Where do concepts come from (5)?

- Problem:
  - Develop a knife that stays sharp

- Blend two concepts

https://www.olfa.co.jp/en/birth_of_olfa_cutter.html (7.9.22)

Taura, T., & Nagai, Y. (2013). *Concept generation for design creativity: A systematized theory and methodology*. London: Springer.

‘Strange’ concepts and their sources

https://disciplesofflight.com/bizarre-aircraft-lippisch-aerodyne/

https://airandspace.si.edu/collection-objects/vought-v-173-flying-pancake/nasm_A19610120000

https://www.aircharterservice.com/about-us/news-features/blog/weird-and-wonderful-concept-planes-that-history-forgot

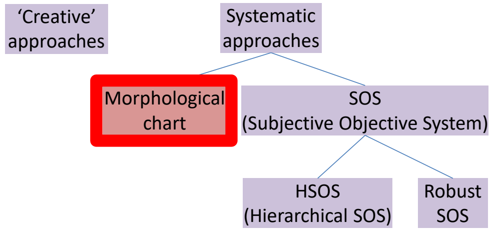
http://stargazer2006.online.fr/aircraft/pages/boomerang.htm

Breaking symmetry

TRIZ, ASIT, …

Systematically generating concepts

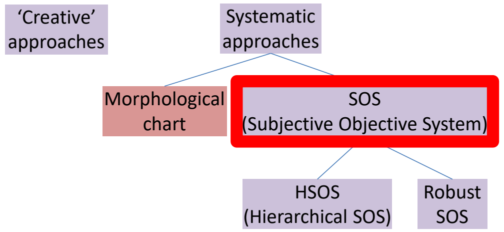
Morphological chart



תתי בעיות	פתרונות אפשריים					
הפחתת האבק שנוצר	הכנה מקדימה של משטח העבודה, חומרי העבודה והציוד	שיטות בניה/ הריסת מבנים חדשות				2
הפחתת האבק שנפלט	*הרטבת משטחי העבודה	שימוש בכלי עבודה סטטיים בעלי מערכת התזת מים	שימוש בכלי עבודה דינאמיים בעלי מערכת התזת מים	*שימוש בחומרים כימיים	שילוב של שני פתרונות *	3
צמצום החשיפה לאבק	בידוד אזורי על ידי מסך (מחסום המונע מעבר אבק)	אמצעי הגנה נשימתית לעובדים	אמצעי הריסת מבנים/ בניית מבנים המאוישים מרחוק	בידוד מאסיבי לשטח		4
איסוף האבק שנפלט	מדחסי אבק תעשייתיים	מדחסי אבק המותקנים ייעודית על כלי העבודה	שילוב של שני הפתרונות			2
הפחתת האבק הנישא באוויר	אוורור חללים פנימיים וחיצוניים	סינון האוויר באזורים מאובקים				2
שינוע האבק הנאגר	שאיבה לכלי קיבול ניידים (משאיות)	שרוול פינוי מאתר הבניה לכלי קיבול על משאית				2
אחסון האבק הנאגר	כלי קיבול ניידים	הטמנה מבוקרת	מיחזור	להשאיר במקום		4

768 מסלולים (פתרונות) אפשריים

Optimal Concept Development



SOS - Subjective Objective System

SOS properties:

- Includes customer, organization, technology, and other inputs
- Avoids known failure modes
- Addresses different markets – product family concept design
- Manages risk – assessment of concept robustness
- Easy to use
- General

A. Ziv-Av and Y. Reich, "SOS – Subjective objective system for generating optimal product concepts." *Design Studies*, 2005.
Y. Reich and A. Ziv-Av, "Robust product concept generation", in *CD-ROM Proceedings of the 15th International Conference on Engineering Design (ICED)*, The Design Society, 2005.

Concept Elements – building blocks (D)

1. Front engine
2. Rear engine
3. Driver before front wheels
4. Driver behind front wheels
5. Front wheel drive
6. Rear wheel drive
7. 4x4 wheel drive
8. Central transmission
9. Rigid axels
10. Independent suspensions

11. Value of building blocks – D = 0,1

Constraints between building blocks

1. Front engine or Rear engine
   (Front engine) + (Rear engine) =1

2. Front, Rear, or 4x4 wheel drive
   Front + Rear + 4x4 = 1

3. 4x4 drive requires central transmission and vice versa
   (4x4 drive) – (central transmission) = 0

4. Driver behind front wheels and Front wheel drive require independent suspension
   (Independent suspension) – ((Driver behind front wheels) + (Front wheel drive)) ≥ -1

Experience in many projects shows that all constraints could be represented by simple linear expressions

Product goals

1. Customer – **objective**
   - Stability and handling
   - Safety in accidents
   - Low cost
   - …
2. Manufacturer – **subjective**
   - Minimal investment/risk in development (for Peugeot, Citroen)
   - Minimal mass production cost
   - Ease of maintenance
   - …

Influence of building blocks on product value

Subjective goal: ***Minimal investment/risk in development***

(for Peugeot, Citroen)

1st order

$$LI(\text{ Front engine }) = \mathbf{1}$$

$$LI(\text{ Rear engine }) = \mathbf{-1}$$

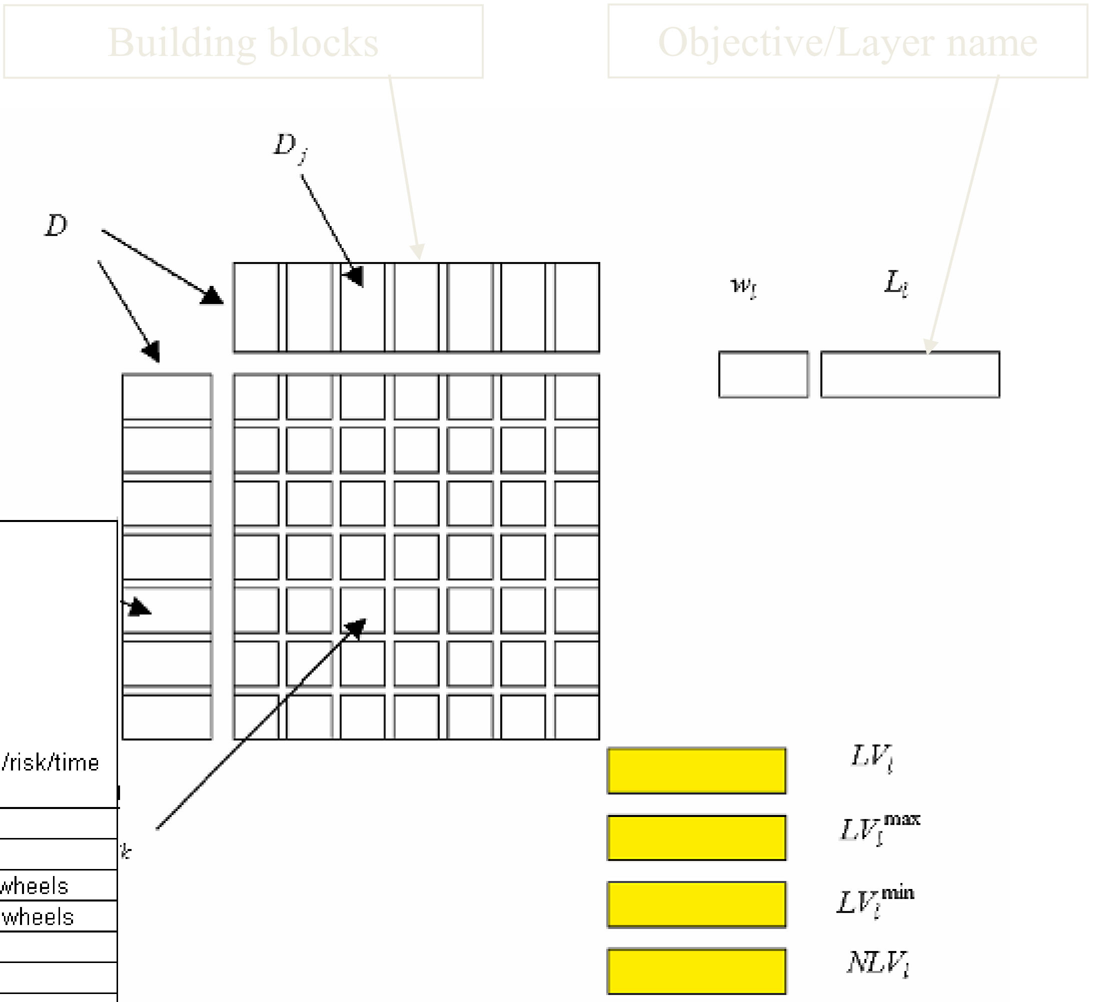
2nd order

$$LI(\text{ 4x4, central transmission}) = \mathbf{-1}$$

$$LI(\text{ Rear engine, Front wheel drive}) = \mathbf{-1}$$

Separation into Decision Layers

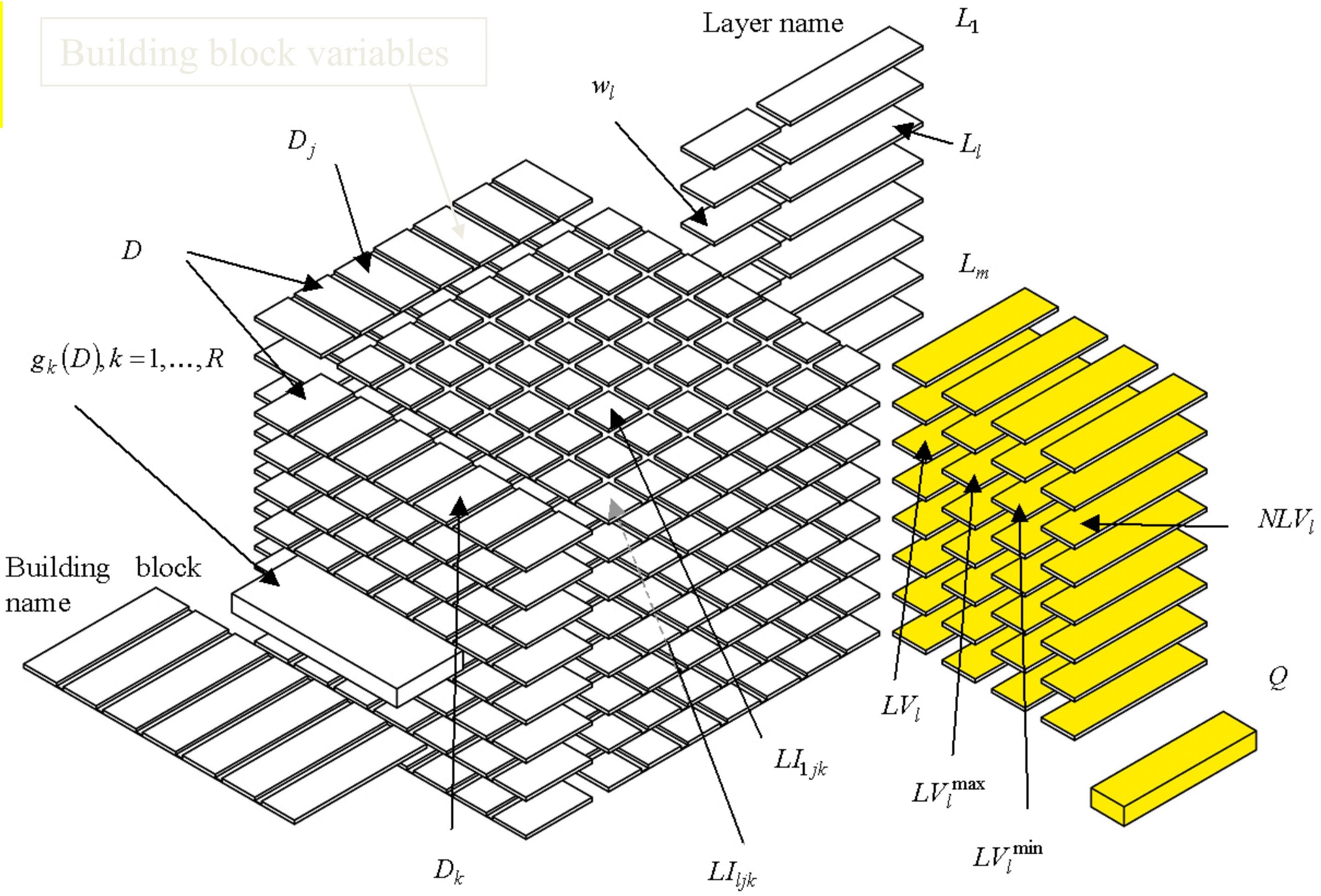
jump



	Independent suspension	Rigid axels	Central transmission	4 wheel drive	Rear drive	Front drive	Driver behind front wheels	Driver before front wheels	Rear engine	Front Engine	Minimal investment/risk/time in development
0.5	0	0	0	0	0	0	0	-1	0	1	Front Engine
-7E-23	0	0	0	0	0	-1	0	0	-1	0	Rear engine
-1E-22	0	0	0	0	0	0	0	-1	0	0	Driver before front wheels
1	0	0	0	0	0	0	1	0	0	0	Driver behind front wheels
0	0	0	0	0	0	1	0	0	0	0	Front drive
-1	0	0	0	0	-1	0	0	0	0	0	Rear drive
-2E-16	0	0	-1	-1	0	0	0	0	0	0	4 wheel drive
-1E-16	0	0	-1	0	0	0	0	0	0	0	Central transmission
-6E-23	0	-1	0	0	0	0	0	0	0	0	Rigid axels
1	1	0	0	0	0	0	0	0	0	0	Independent suspension
1.5	**LV10**										
3	**LV**	**max**									
-7	**LV**	**min**									
0.85	**NLV10**										

Separation into Decision Layers

jump



Contribution toward one product objective

jump

$$LV_l = \sum_{j=1}^{n} D_j \cdot \sum_{k=1}^{n} LI_{ljk} \cdot D_k$$

$$NLV_l = \frac{LV_l - LV_l^{\min}}{LV_l^{\max} - LV_l^{\min}}$$

Mathematical Formulation (basic form)

$$\max Q = \sum_{l=1}^{m} w_l \cdot NLV_l$$

jump

$$NLV_l = \frac{LV_l - LV_l^{\min}}{LV_l^{\max} - LV_l^{\min}}$$

subject to

$$LV_l = \sum_{j=1}^{n} D_j \cdot \sum_{k=1}^{n} LI_{ljk} \cdot D_k$$

$$g_k(D_1,\ldots,D_n) \begin{matrix}\le\\=\\\ge\end{matrix} b_k, k = 1,\ldots,R$$

$$D_j = 0,1,\ j = 1,\ldots,n \qquad \sum_{l=1}^{m} w_l = 1$$

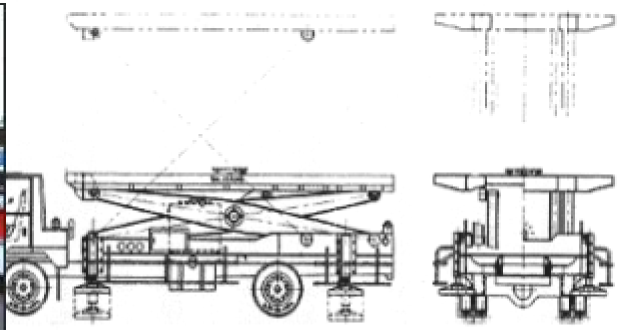
Product objectives: Deck Lifter

Customer/objective requirements

1. Good maneuverability
2. Good operator eyesight
3. Easy entrance into driver compartment
4. Comfortable driver compartment
5. Operators Safety In Malfunction
6. Durability for ship roll loadings
7. Low weight
8. Maintainability

Manufacturer/subjective requirements

1. Min. Mass Production cost
2. Min. Development Investments
3. Mass Production Preparation Investments
4. Max. Design Simplicity
5. Minimum Risks



Hierarchical SOS

Design a concept of an aerial surveillance system

Platform and payload

Rosenstein, D., & Reich, Y. (2011). Hierarchical system concept generation. In *Proceedings of the 18th International Conference on Engineering Design (ICED 11), Lyngby/Copenhagen, Denmark, 15.-19.08. 2011*.

Product objectives - Main Targets

- **Customer/objective requirements**
  1. Survivability of System
  2. High Area Coverage
  3. Long Mission Duration
  4. High Resolution

- **Manufacturer/subjective requirements**
  1. Min. Mass Production cost
  2. Max. Design Simplicity
  3. Minimum Risks

- Later, these targets were decomposed into secondary targets and phrased for the 2nd level articulation of product concept.

Concept Elements – Main Building Blocks (D)

- Two types of main building blocks:
  - **Platform** type
    - Manned Plane
    - Large UAV
    - Small UAV
    - Blimp
  - **Payload** type
    - CCD (Coherent Change Detection)
    - FLIR (Forward Looking Infra-Red)
    - SAR (Synthetic Aperture Radar)
    - Dual Payload (= Combination of two of the payloads listed above)
- Value of building blocks – D = 0,1

Concept Elements – Secondary Building Blocks

- Decomposition of main building blocks into sets of secondary building blocks.

  - **Platform** type secondary building blocks
    - propulsion type,
    - communications,
    - structure and geometry,
    - operational parameters, etc.
  - **Payload** type secondary building blocks
    - stabilization of payload,
    - recording ability,
    - data transmission and compression, etc.

Results – SOS Pareto - Optimal Fronts

- The level 1 concepts are arranged by domination and are sorted into Pareto-fronts.
- Best concepts (non-dominated) are highlighted.

DA Platform	DA Payload	Domination	Dominated by	Front
Blimp	CCD	Non-Dominated		1
Blimp	FLIR	Dominated Solution	3, 11, 1, 7, 8	3
Small UAV	CCD	Non-Dominated		1
Small UAV	FLIR	Dominated Solution	3	2
Large UAV	DUAL SENSOR	Non-Dominated		1
Large UAV	SAR	Non-Dominated		1
Large UAV	CCD	Non-Dominated		1
Large UAV	FLIR	Dominated Solution	11, 7, 3	2
Manned Plane	DUAL SENSOR	Non-Dominated		1
Manned Plane	SAR	Non-Dominated		1
Manned Plane	CCD	Non-Dominated		1
Manned Plane	FLIR	Dominated Solution	11	2

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Robust Product Concept

Robust product concept is an integrated collection of solution principles or technologies that provide the basis for solving a design problem that is indifferent to small changes in the requirements

Commercial passenger aircraft concepts

Robust

???

Globally robust concept - example

1. Problem definition – partial information

Building Blocks	Product Requirements
1. Front Engine	1. Handling & stability
2. Rear engine	2. Comfort (Min. jostling)
3. Driver location before front wheels	3. Accident safety
4. Driver location behind front wheels	4. Off road maneuverability
5. Front drive	5. Minimal turning radius
6. Rear drive	6. Easy maintenance
7. 4 wheel drive	7. Min. investments
8. Central transmission	8. Min. production cost
9. Rigid axels	
10. Independent suspension	

2. Uncertainty in consumer preferences ***w***

Globally robust concept - example

1. Randomly sampling 100 ***w*** vectors

2. Robust product concepts in descending order of global robustness:

	Number of occurrences					
1	46	Front engine	Driver behind	Rear drive	Independent suspension	
2	26	Front engine	Driver behind	Rear drive	Rigid axels	
3	20	Front engine	Driver behind	Front drive	Independent suspension	
4	4	Front engine	Driver before	Rear drive	Rigid axels	
5	1	Front engine	Driver before	Rear drive	Independent suspension	
6	1	Front engine	Driver behind	4 wheel drive	Independent suspension	Central transfer
7	1	Rear engine	Driver behind	Rear drive	Independent suspension	
8	0	Rear engine	Driver behind	Rear drive	Rigid axels	
9	0	Rear engine	Driver behind	4 wheel drive	Independent suspension	Central transfer
10	0	Rear engine	Driver before	4 wheel drive	Rigid suspension	Central transfer

Globally robust concept - example

1. In this case, globally robust concepts are also good across diverse markets

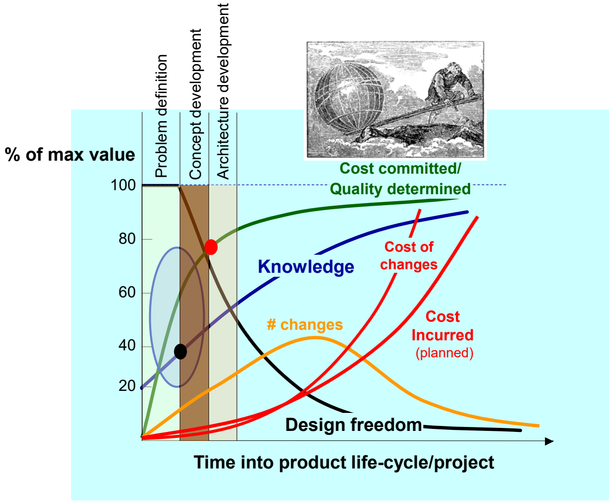
Market definitions
(Data from customer surveys)

	Requirement	Relative weight of requirements			
		1	2	3	4
1	Handling & stability	2	3	0	3
2	Comfort (Min. jostling)	2	3	0	3
3	Accident safety	2	3	0	2
4	Off road maneuverability	1	3	0	1
5	Minimal turning radius	1	1	3	1
6	Easy maintenance	2	1	3	2
7	Min. investment & risk	2	0	3	2
	Concept (Table 2)	Normalized quality			
1	1	100%	92%		
2	2	96%			86%
3	3	92%	96%		100%
4	4			100%	
5	5			88%	
6	6		100%		
7	7			76%	72%
8	8		0%		
9	9			0%	
10	10	0%			0%

Detailed analysis reveals that less frequent concepts could be more robust

Summary

“Give me a good concept, and I will move the earth”



- ‘Creative’ approaches
- Systematic approaches
  - Morphological chart
  - SOS (Subjective Objective System)
    - HSOS (Hierarchical SOS)
    - Robust SOS

References

1. Cohen, Y. H., & Reich, Y. (2016). *Biomimetic design method for innovation and sustainability* (Vol. 10). Berlin, Germany: Springer.
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11. A. Ziv-Av and Y. Reich, "SOS – Subjective objective system for generating optimal product concepts." *Design Studies*, 2005.