Principles of Axiomatic Design and their Application

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B. Domain mapping
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E. Design Axioms
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F. Application of Axiomatic design

A. Axiomatic Design THEORY

- By Nam Suh at MIT in Mechanical engineering at 70s.
- Axiomatic design is not really a process. It is a theory!
- Systematic matrix-based mapping process b/w domains from Customer needs to design solutions and to ”production”
- Based on design principles / Axioms.
- Supports Taguchi methods, DSM, Design for Six sigma, etc…

A. Axiomatic Design THEORY

- **What** we want to achieve & **How** we want to achieve (Suh)
- What kind of problems / opportunities exist in the real world?
- Ill defined problems and hidden opportunities with many answers.

Suh (2001). *Axiomatic Design: Advances and Applications*, Oxford University Press, 2001, ISBN 0-19-513466-4

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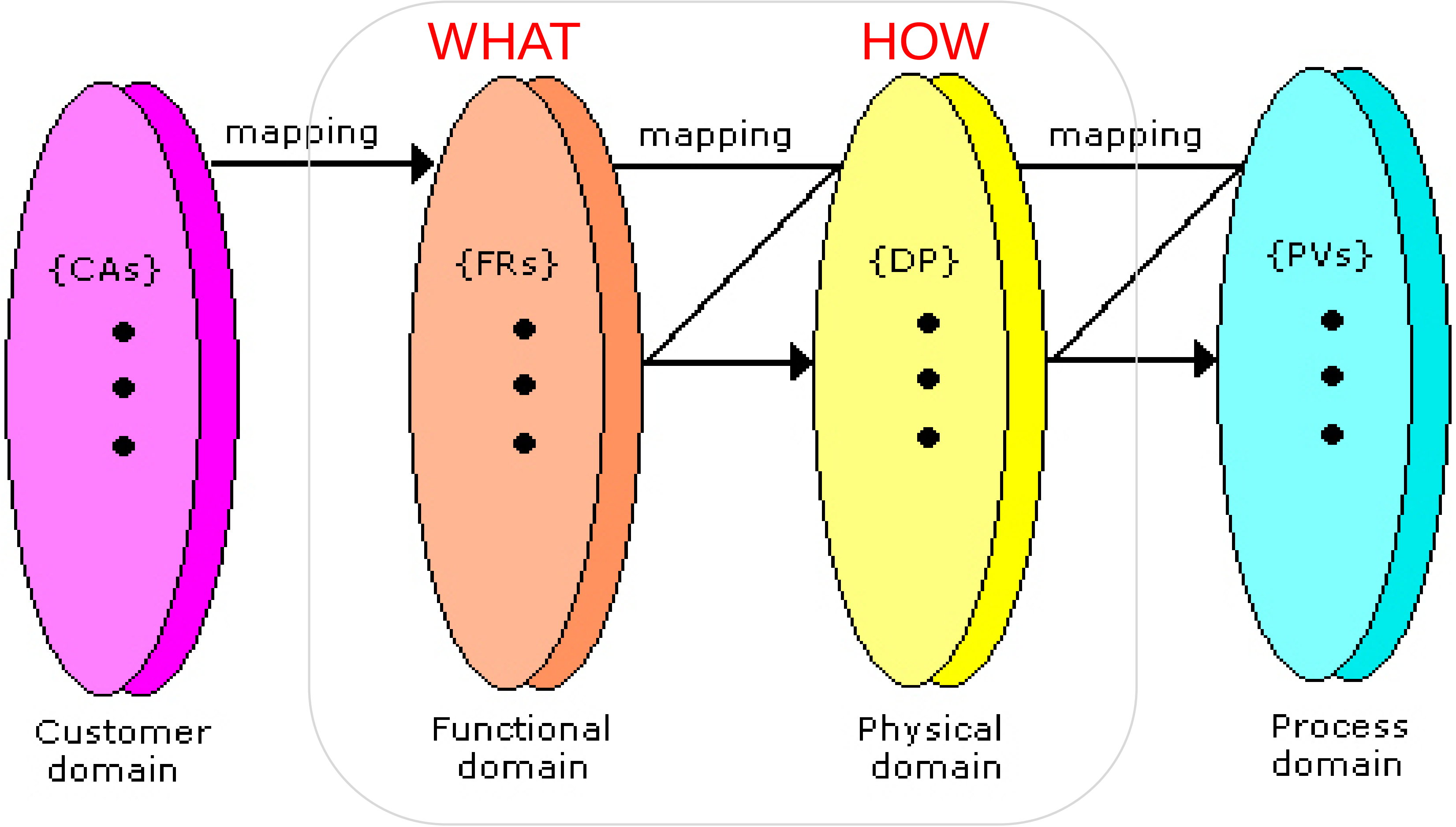
B. Domain mapping



Design: WHAT we want to achieve & HOW we want to achieve it (Suh 2001)

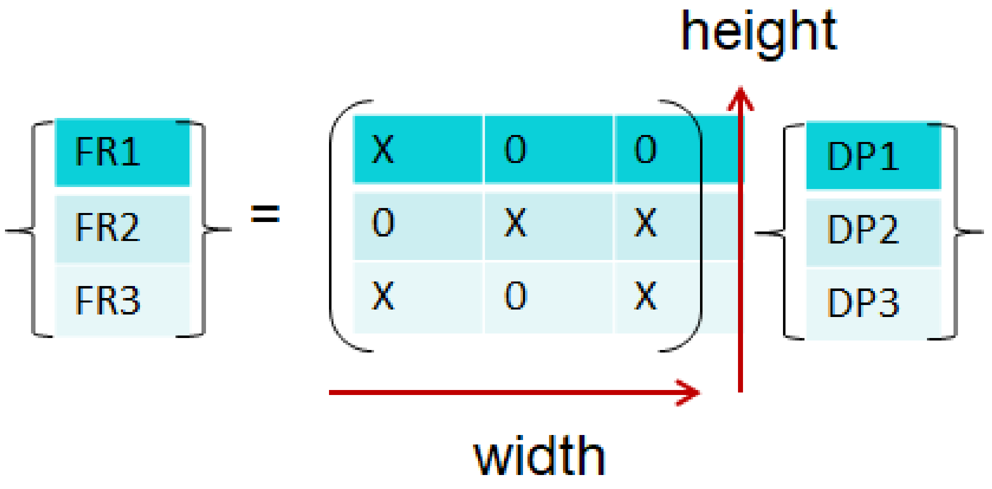
B. Domain mapping

- CA: Stakeholders and their Needs
- FR: The minimum set of independent requirements that completely characterizes the functional needs of the artifact
- DP: The key physical or logical variables in the physical/logical domain that characterize the design that satisfies the specified FRs.
- PV: How to bring to life

C. Design Matrices

- Vector of FRs {FR} -> WHAT
- Vector of DPs {DP} -> HOW
- Design matrix = [A]
- The relationship b/w the vectors {FR} =[A] {DP}

- Visual / logical relationship:
  X = relationship
  O = no relationship
  Equations = numerical relationship



C. Design Matrices

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{pmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$$

Uncoupled – Best

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{pmatrix} X & 0 & 0 \\ X & X & 0 \\ X & o & X \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$$

Decoupled – OK

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{pmatrix} X & X & X \\ X & X & 0 \\ X & X & X \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$$

Coupled – Bad

D. An Example

A water facet (Suh 2001):

FR1: Control water temperature
FR2: Control water flow

DP1 Cold water handle
DP2 Hot water handle

Or

DP1 Temperature handle
DP2 Flow handle

D. An Example

A water facet (Suh 2001):

FR1: Control water temperature
FR2: Control water flow

DP1 Cold water handle
DP2 Hot water handle

Not independent

Or

DP1 Flow handle
DP2 Temperature handle

Independent

Coupled

	DP1	DP2
FR1	X	X
FR2	X	X

Uncoupled

	DP1	DP2
FR1	X	
FR2		X

E. Design Axioms

The two design axioms (Suh 1990) are:

1. Axiom: **The Independence Axiom**: Maintain the independence of the functional requirements.

2. Axiom: **The Information Axiom**: Minimize the information content of the design.

1. Independence Axiom

- Maintain independence through the design process.
- How you choose DPs can make FRs independent / dependent from each other.
- When you decompose your design, it becomes more difficult to keep FRs independent.

1. Independence Axiom

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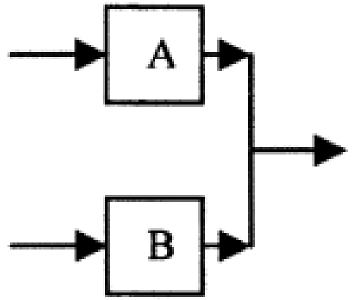
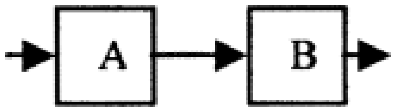
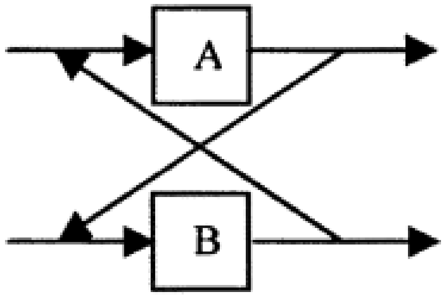
<tr><th colspan="4">Three configuration that characterise a system</th></tr>
<tr><th>Relationship</th><th>Parallel</th><th>Sequential</th><th>Coupled</th></tr>
<tr><td>Graph Representation</td><td>
</td><td>
</td><td>
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<tr><td>DSM Representation</td>
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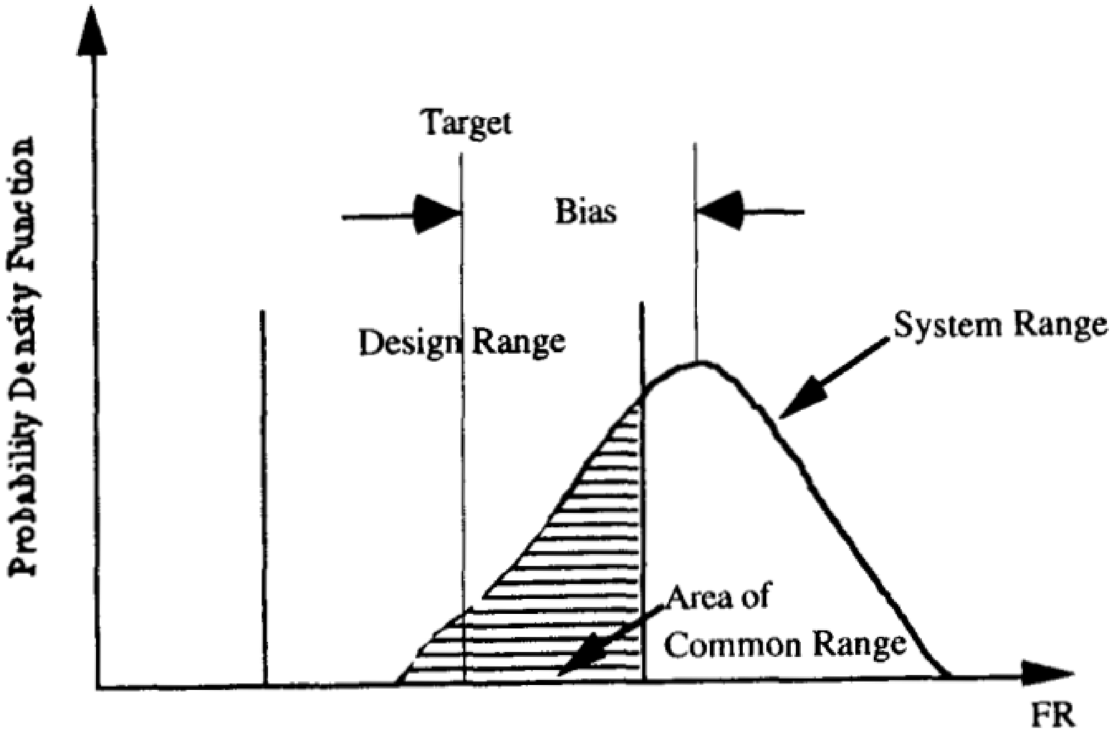
(Guenov and Barke, 2005)

2. Information Axiom



(Suh 1995)

- **Design range** is the tolerance within which the DP can vary
- **System range** is the capability of the (manufacturing) system
- **Common range** is the overlap between design and system ranges, and specifies the range within which the FR(s) can be met.

2. Information Axiom

- $I = \sum_{i=1}^{n} - \mathrm{Log}\,(p_i)$, where $p_i = \Pr\{DP_i \text{ satisfies } FR_i\}$
- The design that has the least information content is the best design!
- This is done by:
  - Making the design more simple -> reduce coupling
  - Increasing the tolerances of the design

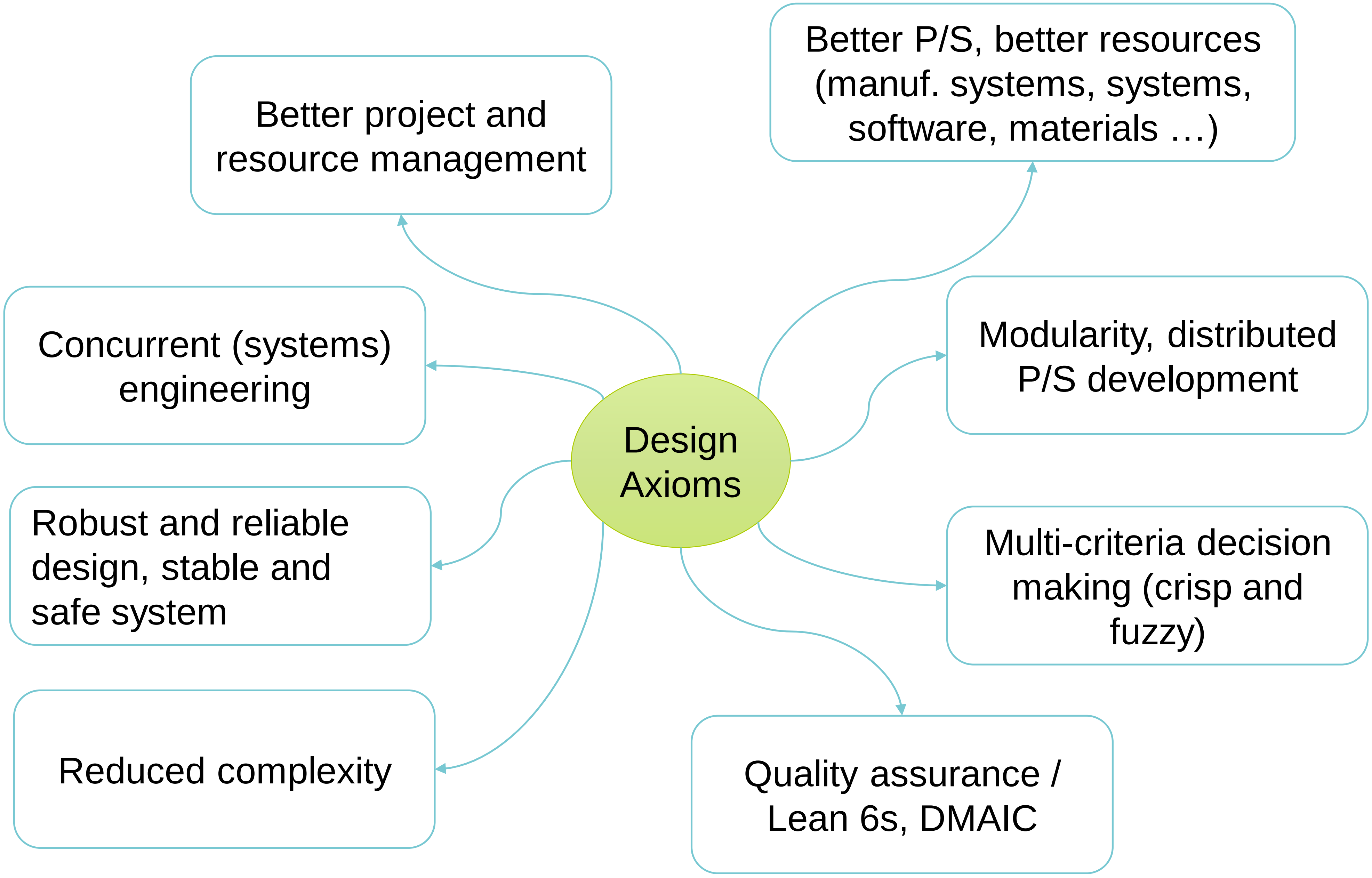
(Suh 1990, 2001)

F. Application of AD (Suh)

1. Recognize the existence of domains
2. Design involves mapping b/w domains
3. Define FRs and associated Constraints (Cs)
4. Design equation FR = DM * DP and the independence of FRs
5. Decompose FRs and DPs
6. Check Constraints
7. Information axiom
8. Physical integration of DPs
9. Non-hardware design

F. Application of AD	Customer {CAs}	Functional {FRs}	Physical {DPs}	Process {PVs}
Manufacturing	Attributes which consumers desire	FRs specified for the product	Physical variables which can satisfy the FRs	Process variables that can control DPs
Materials	Desired performance	Required Properties	Micro-structure	Processes
Software	Attributes desired in the software	Output, Spec of prog codes	Input variables or algorithms, modules, prog. codes	Sub-routines, machine codes, compilers, modules
Organization	Customer satisfaction	Functions of the organization	Programs or offices	People and other resources that can support the programs
Systems	Attributes desired of the overall system	FRs of the system	Machines or components, sub-components	Resources (human, financial, materials, etc.)

F. Application



F. When to apply?

- Opportunities for new P/S, resources, systems, organizations, etc. are constantly emerging.
- Existing Artefacts need updating.
- Well worth to check Your P/S, systems, etc. with AD!
- Contact UTU / ME dept. (Jussi.Kantola@utu.fi, 050 570 6520) for support.
- Several ways we can support: theses, projects, internships, consulting, etc.

References

- Guenov, M.D. and Barker, S.G. (2004), Application of axiomatic design and design structure matrix to the decomposition of engineering systems. Syst. Engin., 8: 29-40. doi:10.1002/sys.20015
- Kulak, O., Cebi, S. and Kahraman, C., Applications of axiomatic design principles: A literature review, Expert Systems with Applications, 2010, pp. 6705-6717
- Suh, N.P. (1990), The principles of design, Oxford University Press, New York
- Suh, N.P., (1995), Designing-in of Quality Through Axiomatic Design, IEEE Transactions on reliability, 44(2)
- Suh, N.P. (2001), *Axiomatic Design: Advances and Applications*, Oxford University Press, 2001, ISBN 0-19-513466-4
- Suh, N.P. (1995)Design and operation of large systems. J. Manuf. Syst. 14(3)
- Suh, N.P. (2005) Complexity : Theory and Applications (Oxford University Press, New York

- https://axiomaticdesign.com/technology/papers.asp

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