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A proposed taxonomy of physical prototypes: structure and validation

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Overview of the presentation

- Motivation
  - Definition of prototype
  - Purpose of physical prototype
  - Need for prototype taxonomy
- Taxonomy of physical prototype
  - Factors of prototype
    - Communication
    - Evaluation purpose
    - Cost
    - Design stage
  - Characteristics of prototype
    - Size
    - Type
    - Material
    - Fabrication
- Taxonomy validation
  - Orthogonality matrix
  - Benchmark against existing ‘classifications’
  - Demonstration of its utility to classify different prototypes
- Conclusion
  - Findings and future work

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Motivation

- Definition of Prototype
  - A prototype is a physical instantiation of a product, meant to be used to help resolve one or more issues during product development [3, 4]
- Purpose of Prototype [Ulrich & Eppinger]
  - Learning
    - Identify unknowns during product development
      - Some unknowns may include: customer satisfaction, functionality, or feasibility of the prototype
  - Communication
    - Able to communicate to different groups within a product development team
    - Convey design intent effectively when compared to sketches, 3-D drawings, and other design representations
  - Integration
    - Verify the assembly of components and subsystems of a product
    - Verify the fit and assembly sequence of the design before preceding to full scale production
      - Builds confidence about the design and its manufacturability
  - Milestones
    - Helps keep track of product development by meeting desired goals and deliverables
      - Prove to management the project is on schedule
    - Demonstrate a particular level of functionality

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Motivation

- Need for prototype taxonomy
  - Little is known about when and what types of prototypes should be built throughout the design process
  - What is known is typically internal to the company and/or individual and based on empirical, anecdotal, or experiential knowledge
  - Currently, there are no taxonomies of prototypes which clearly and consistently capture the characteristics and purposes of prototypes [1-3]

- Taxonomy
  - Definition: The science of classification
  - Supports the transmission, clarification, and organization of large amounts of information [4-6]

- A Prototype Taxonomy will
  - Obtain a common, shared understanding of prototypes
  - Allow designers to build prototypes in an effective manner.
    - Reduce the complexities involved with prototype fabrication and selection

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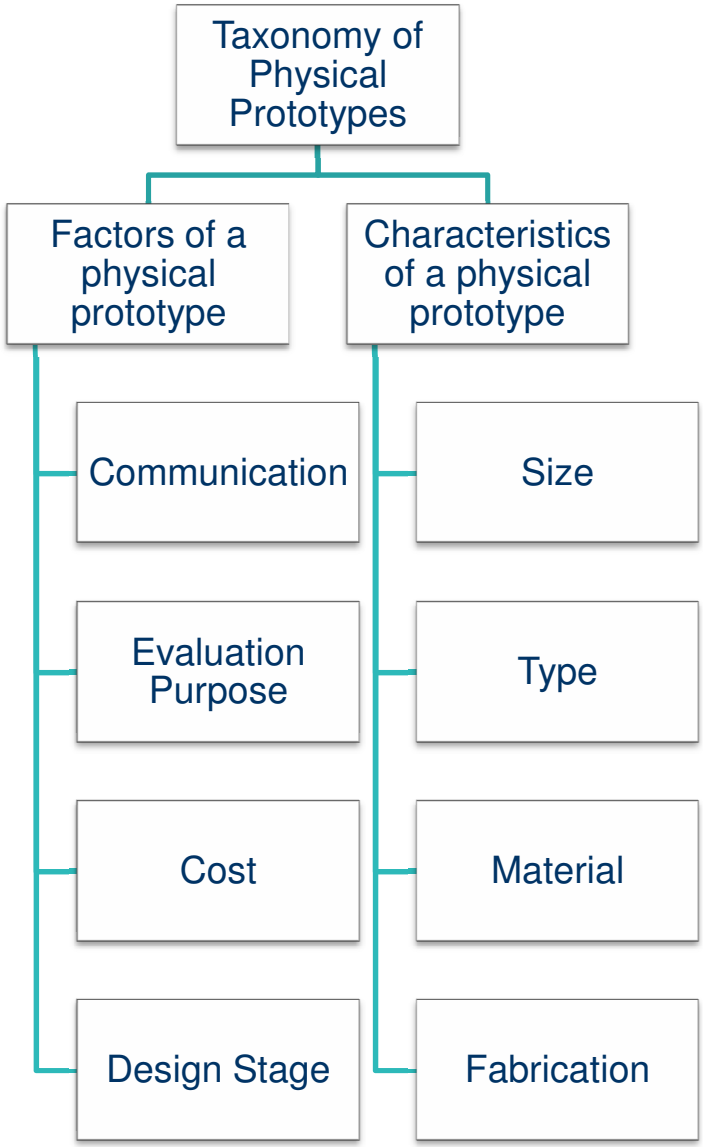
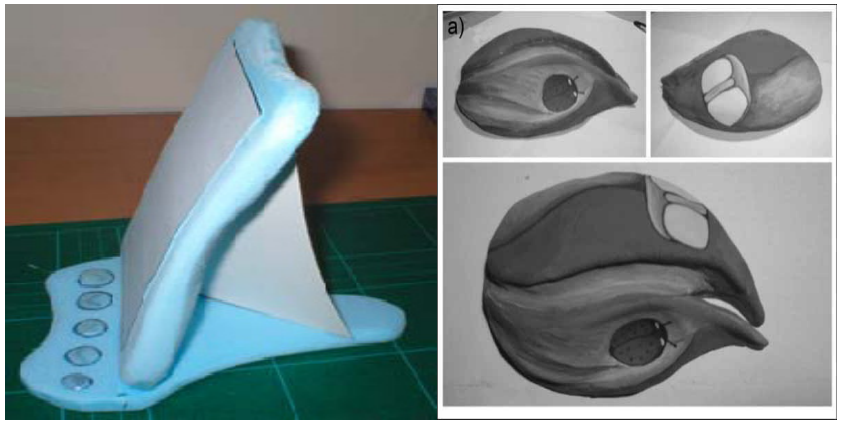
Taxonomy of Physical Prototypes: Overview



- Taxonomy of prototype is divided into two main categories
  - Factors of a physical prototype
    - The factors taken into account when fabricating the physical prototype
      - Example: Communication intent- Propose new concepts
  - Characteristics of a physical prototype
    - The resulting characteristics of prototype due to the factors taken into account during fabrication
      - Example: Material – Foam core or modeling clay



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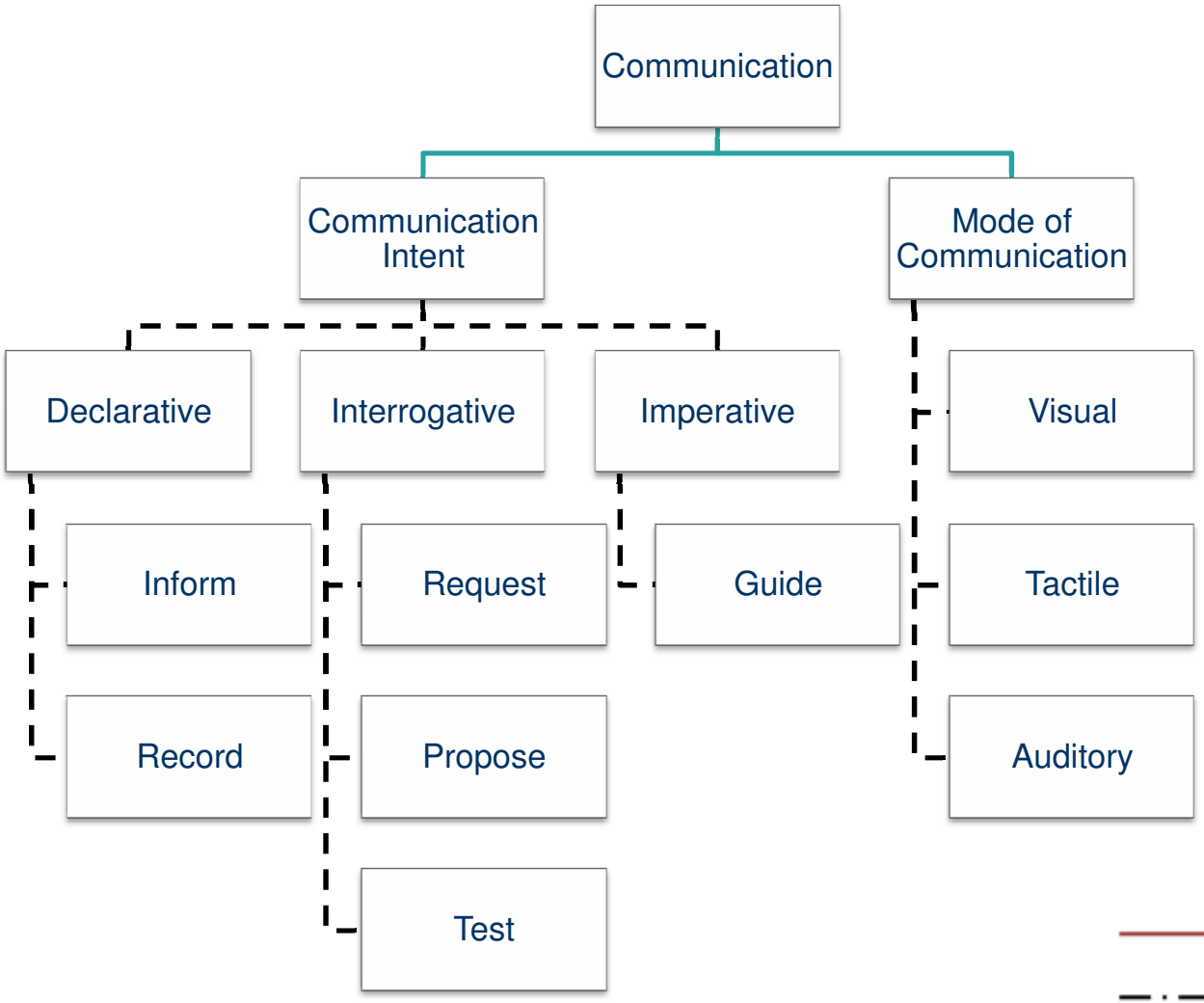
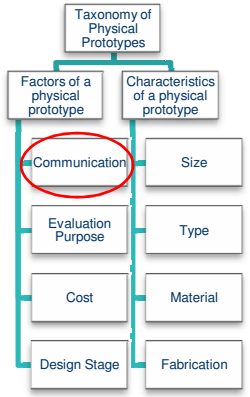
Factors of a prototype: Communication





Use All the taxons

Choose One of the taxons

Choose One or multiple taxons

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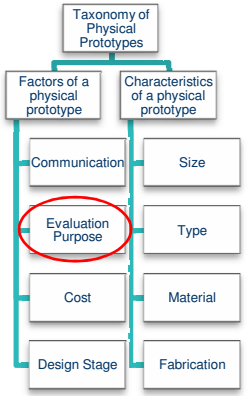
Factors of a Prototype: Evaluation Purpose



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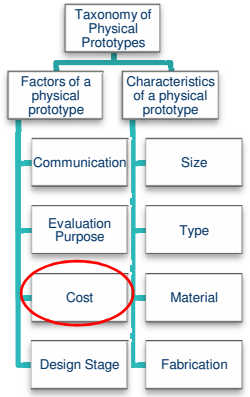
Factors of a Prototype: Cost



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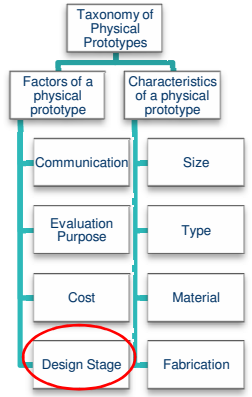
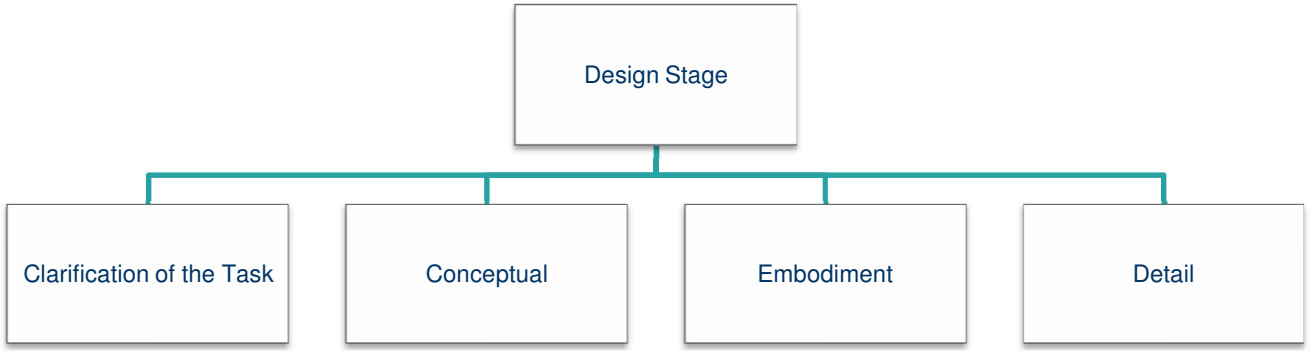
Factors of a Prototype: Design Stage





Use All the taxons

Choose One of the taxons

Choose One or multiple taxons

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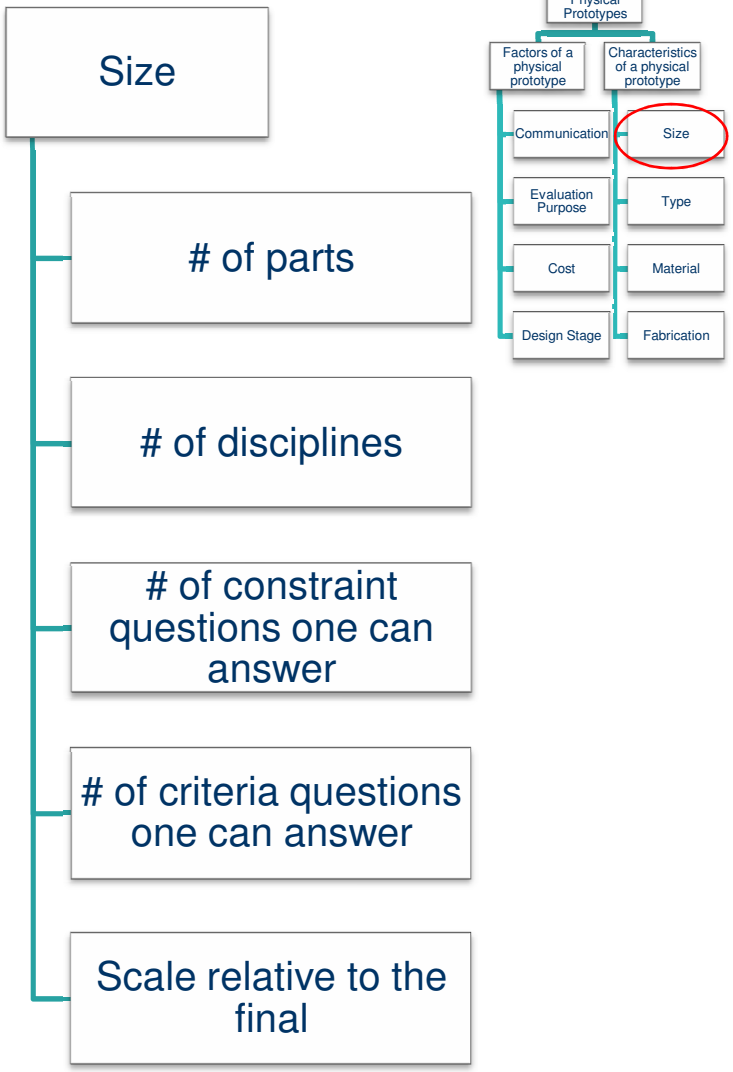
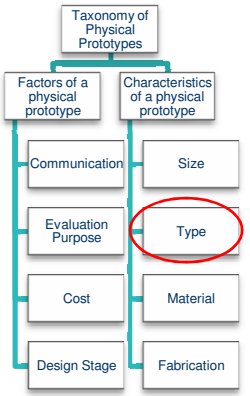
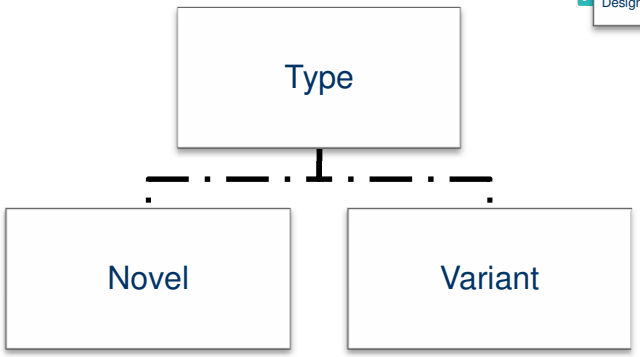
Characteristics of a Physical Prototype: Size & Type







Use All the taxons

Choose One of the taxons

Choose One or multiple taxons

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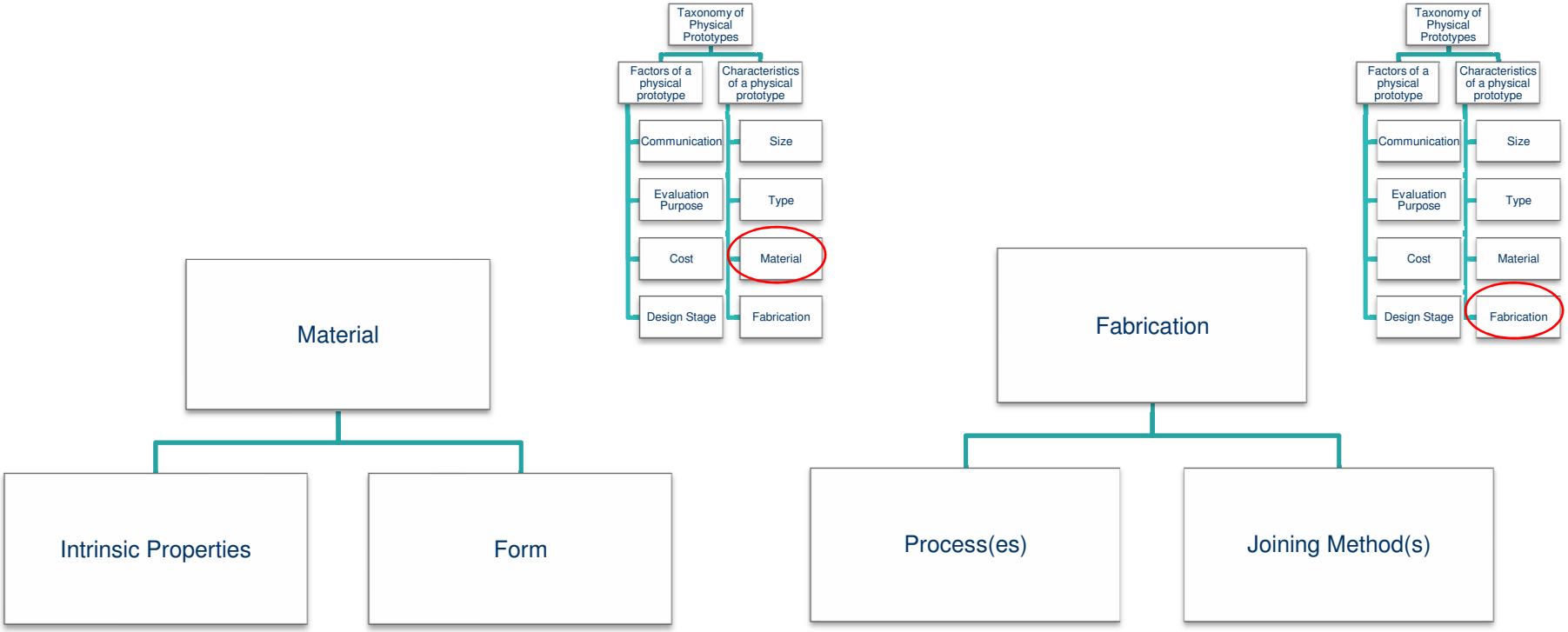
Characteristics of a Physical Prototype: Material & Fabrication



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Taxonomy Validation: Orthogonality Matrix

Physcial Prototype Taxonomy Orthogonality Matrix
0 has no dependence
1 has some dependence

Factors of a physcial prototype	Communication	Evaluation Purpose	Cost	Design Stage	Characteristics of a physical prototype	Size	Type	Material	Fabrication
Factors of a Physical Prototype									
Communication									
Evaluation Purpose	1								
Cost	0	0							
Design Stage	0	1	1						
Characteristics of a physical prototype									
Size	1	1	1	0					
Type	0	0	0	0		0			
Material	1	1	1	0		1	0		
Fabrication	1	1	1	0		1	0	1	

- Orthogonality Matrix is used to identify interdependencies between taxons
  - The taxons which are mutually exclusive are represented by ‘0’
  - The taxons which are not mutually exclusive are represented by ‘1’
- Interdependencies between taxons are identified
  - Reason – ‘The factors taken into account when fabricating a prototype should prescribe the characteristics of that prototype’

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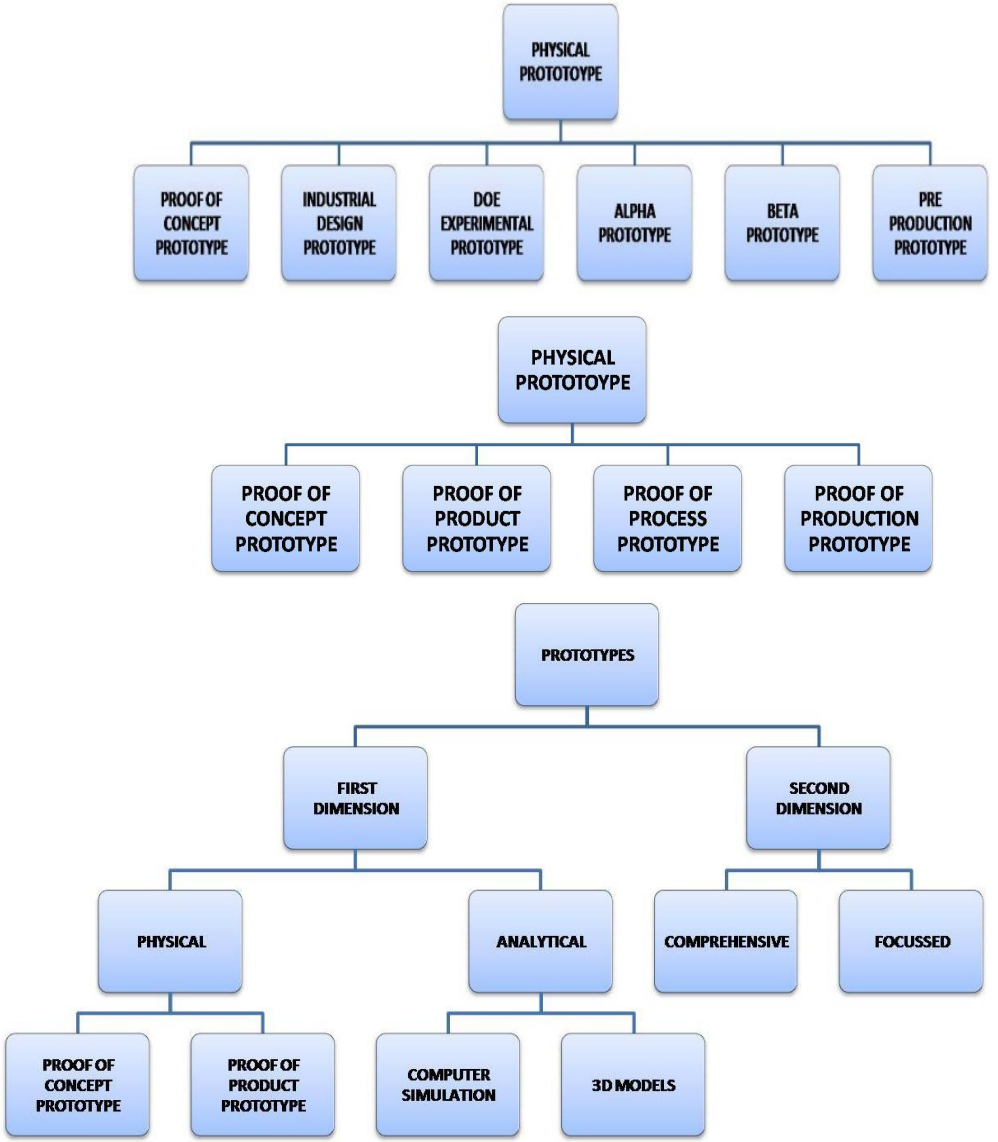
Taxonomy Validation: Benchmark against existing 'classifications'

- Otto and Wood
  - Six high level classification based on design intent or purpose
  - Beta prototype and Pre-production prototype show overlap in terms of material and production processes
- Ullman
  - Classification based on the purpose of the prototype
  - Further generalizes prototypes to four categories leading to overlap between prototype classifications
- Ulrich and Eppinger
  - Two dimensions
  - Physical prototypes – classified into two groups
  - Higher overlap than other two classifications



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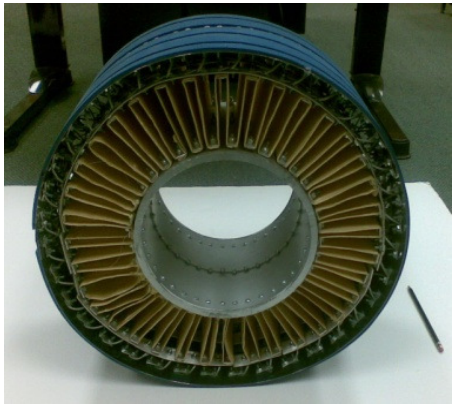
Taxonomy Validation: Demonstration of its utility to classify different prototypes

Factors of physical prototype

- Communication intent
  - Declarative – *Inform*
  - Interrogative – *Test*
  - Imperative – *Guide*
- Mode of Communication
  - Visual
- Evaluation Purpose
  - Single design
    - Form – *Acceptable*
    - Function – *Good*
    - Fit – *Satisfactory*
- Cost
  - Time
    - Fabrication – *200 Man-hours*
    - Procurement – *1 week*
  - Internal resources
    - Material - $ 0
    - Fabrication - $ 2000
    - Joining method - $ 300
- External resources
    - Material - $ 1500
    - Fabrication - $ 0
  - Joining method - $ 0
- Design Stage
  - Embodiment



Helical Coil Non-Pneumatic Wheel Prototype

Characteristics of physical prototype

- Size
  - No. of parts relative to the final product – *Same*
  - No. of disciplines – Single
  - No. of constraints met – 2
  - No. of criteria met – 2
  - Scale of prototype – *1:1*
- Type
  - Variant
- Material
  - Intrinsic properties
    - Min. Operating Temperature – 140 K
    - Max. Operating Temperature – 400 K
- Form
  - Post processed – *sheets and coils*
- Fabrication
  - Process
    - Forming
- Joining Method

  Springs, nuts and bolts

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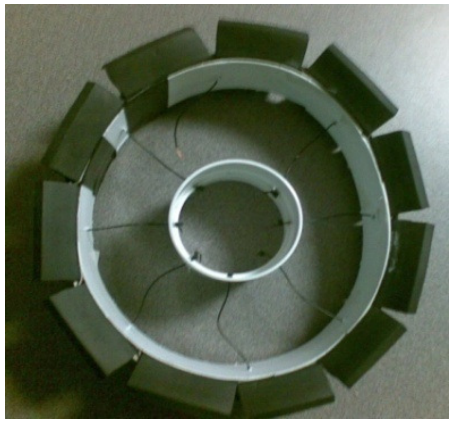
Taxonomy Validation: Demonstration of its utility to classify different prototypes

Factors of physical prototype

- Communication intent
  - Declarative – *Inform*
  - Interrogative – *Propose*
  - Imperative – *Commit*
- Mode of Communication
  - Visual
- Evaluation Purpose
  - Single design
    - Form – *Acceptable*
    - Function – *Poor*
    - Fit – *Poor*
- Cost
  - Time
    - Fabrication – *5Man-hours*
    - Procurement – *1/2 day*
  - Internal resources
    - Material - $ 0
    - Fabrication - $ 0
    - Joining method - $ 0
- External resources
    - Material - $ 80
    - Fabrication - $ 0
  - Joining method - $ 0
- Design Stage
  - Conceptual



Plastic NPW Prototype for Traction Concept

Characteristics of physical prototype

- Size
  - No. of parts relative to the final product – *low*
  - No. of disciplines – *Single*
  - No. of constraints met – *1*
  - No. of criteria met – *1*
  - Scale of prototype – *1:1*
- Type
  - Novel
- Material
  - Intrinsic properties
    - Strength – *low*
    - Rigidity – *low*
- Form
  - Post processed – *Rubber and Plastic*
- Fabrication
  - Process
    - Forming
- Joining Method
  - Adhesive bonding

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Conclusion and Future Work

- The proposed taxonomy
  - is capable of distinguishing between prototypes with greater precision than what is possible with current classifications.
  - is validated by three different approaches
    - Orthogonality check revealed interdependencies between taxons due to inherent properties of the taxons
    - Current classifications are insufficient to accurately describe characteristics of prototypes
    - Two different prototypes of varying levels of detail were classified using the proposed taxonomy
  - shows a correlation between the factors taken into account when fabricating a prototype and the characteristics of that prototype.

- Future Work
  - Design tool and data base for selecting prototypes depending on user needs
  - Conduct design of experiment to identify level of detail necessary to select the appropriate prototype(s) to build with a specified evaluation intent
    - Ex: Constructing a high level of detail prototype to determine safety issues (evaluation intent)

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References

1. Otto K. N., and Wood K. L., 2001, *Product design: Techniques in reverse engineering and new product development*, Prentice-Hall, Inc. New Jersey, USA.
2. Ulrich K. T., and Eppinger S. D., 2000, *Product design and development*, McGraw-Hill, Inc, USA.
3. Ullman D. G., 2002, *The mechanical design process*, McGraw-Hill Professional, USA.
4. Jeffrey, C., 1982, *An Introduction to Plant Taxonomy*, Cambridge University Press, New York, USA.
5. Derr, R., 1973, *A Taxonomy of Social Purposes of Public Schools*, McKay Publishing, New York, USA.
6. Gershenson, J., and Stauffer, L., 1999, "Taxonomy for design requirements from corporate customers", Research in Engineering Design, **11**(2), pp. 103-105.

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Taxonomy of Prototypes

Factors of a Physical Prototype			
Communication	Intent	Declarative *(Inform, Record)*	[17- 20]
		Interrogative *(Request, Propose, Test)*	
		Imperative *(Guide, Commit, Decide)*	
	Mode of Communication *(Visual, Tactile, Auditory, Mixed)*		
Evaluation Purpose	Single Design	Form *(Is it acceptable, what is good/bad)*	[3, 4, 5, 21, 22, 27, 28]
		Function *(Does it function, how well does it perform)*	
		Fit *(will it fit, how well does it fit)*	
	Multiple Designs	Form *(which ones are acceptable, which one has better visual, tactile, and/or auditory appeal)*	
		Function *(which ones work, which one performs better)*	
		Fit *(which ones fit, which ones fit better)*	
Cost	Time *(fabrication, procurement)*		[23- 25]
	Availability *(internal resources, external resources)*		
Design Stage *(Clarification of the task, conceptual, embodiment, detailed, production)*			[4, 5, 21, 24, 26, 27]
Characteristics of a Physical Prototype			
Size	Number of Parts relative to the final sub-system		[28, 29]
	Number of disciplines		
	Number of constraint questions that can be answered		
	Number of criteria questions that can be answered		
	Relative scale (dimensioned) to final		
Type *(Novel, Variant)*			[21, 29, 30]
Material	Intrinsic Properties		[3, 25, 31, 32]
	Processed Form		
Fabrication	Joining methods		[31, 32]
	Part production processes		

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NPW Benchmark comparison

Classification	Helical coil NPW	Plastic NPW
Otto and Wood	➢ ***DOE/Beta prototype***	➢ ***Proof of concept prototype***
Ullman	➢ ***Proof of product/production prototype***	➢ ***Proof of concept prototype***
Ulrich and Eppinger	○ First dimension • Physical ➢ ***Proof of product prototype*** ○ Second dimension • Comprehensive	○ First dimension • Physical ➢ ***Proof of concept prototype*** ○ Second dimension • Focused

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