AC 2011-1906: EXAMINATION OF A METHOD FOR DETERMINING WHEN TO DEVELOP TRANSFORMABLE PRODUCTS THROUGH DESIGN STUDIES

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Examination of a Method for Determining When to Develop Transformable Products through Design Studies

Abstract

Transformable products (or transformers), *those with two or more functional states*, are increasingly utilized by our society. As the mobility and complexity of life increases, so must the adaptability of the products which we use. To develop more adaptable products and systems, new design techniques are needed. These techniques should be developed through sound research methodologies and enhance designers abilities. Toward this end, we have developed a set of indicators which classify design problems between those for which the preferable design is a **transformer**, devices with multiple functional states, or a **monomorph**, devices with a single functional state. The indicators reveal, at an early stage in the design process, if developing a transformable product is likely to be advantageous. A novel design methodology is proposed which incorporates the indicators and has been tested at teaching institutions of higher education. Design application trials are used as a method for determining the impact of this technique on the design process. Surveys were disseminated to student teams at the educational institutions. The survey is used to explain the methodology to students and report results to our researchers. The method assesses design contexts into archetypes. Once mapped to an archetypical design problem, ideal for either transformer or monomorph design, distinct suites of concept generation tools are suggested to accelerate the design process. This process leads to high quantities and novelty of design concepts. The experiment compares the archetypical prediction with the experimental control of actualized results and intra-team consistency of design problem assessment. Based on experimental results, the indicator technique for transformer design is validated and the presented design tool is affirmed. A combined empirical and deductive design research method supports this experiment. Interactions of the experiment also provides links between undergraduate students and graduate level research processes.

Introduction

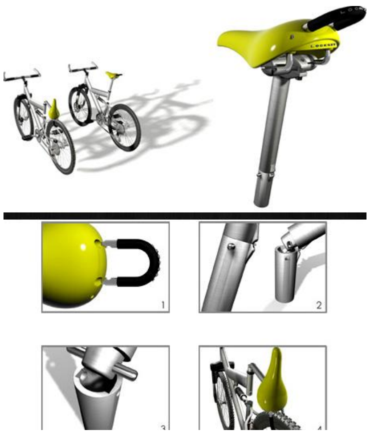
Products continue to integrate into our lives. Thus more and more distinctions can be made about what kinds of products are needed for various circumstances. The distinction in which we place interest is whether a preferable product is one that can transform, that is change shape and functionality, or one which maintains a consistent morphology. We want to establish design methods to ensure this distinction of needs is properly met.

For most instances of design, decisions of whether to include a transformation have been made using indirect or intuitive mechanisms. We have proposed a novel method which formalizes this decision [1]. There is precedent for this type of formalization to occur. The recent development of design methodologies, or tools which aid the designer in concept generation and selection, has followed a similar progression from the intuitive to the formal [2]. Formal methods retain and broaden the designers innate artistic ability while simplifying the selection process.

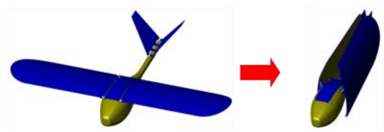
The experiment described in this paper investigates the effectiveness of our design method for making the decision above. The experiment also provided students with an enhanced understanding of design. A study was implemented in a mechanical engineering senior design course. The first half of the study included giving students a survey. The survey includes the method alluded to above, seen in Appendix A, for determining whether to develop a transformable product or not. The second half of the study includes examining the solution form actually chosen by the students. We examine the correlation between prediction and embodiment. We also consider the similarity of problem description among team members. Similarity of problem description is examined to ensure that students are approaching the method from a common conceptual framework.

Definitions of Transformer and Monomorph

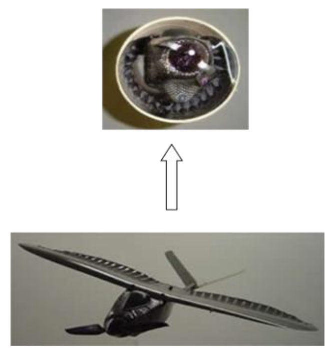
Research into transforming systems has led us to define a transformer as *a system that exhibits a state change in order to facilitate a new functionality or enhance an existing functionality* [2]. A state of a system is defined as *a specific physical configuration in which a system performs a function* [2]. Figure 1 presents several novel transformer designs.



Bike Seat / Bike Lock Transformer [3] by permission



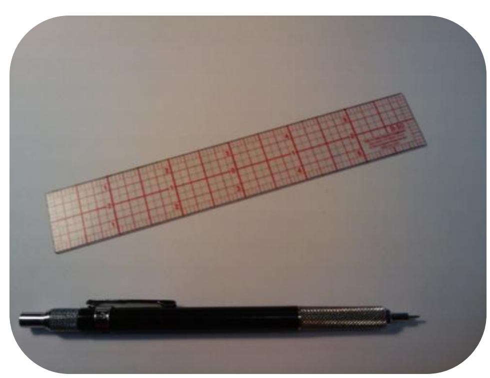
TAC MAV Folding Wing Concept [2]



Bat MAV Rolling Wing [2]

Figure 1: Example Transformer Designs

In contrast to transformers, primary function or monomorph devices, *those which maintain a consistent primary geometric form to apply their essential functions*, are those which do not change primary state. Devices which are monomorphs may have relative motion between components. Yet, they have no distinctive structural reorientation to modulate function. Figure 3 represents example monomorphs. These devices can be developed using traditional design methodologies such as found in texts of design methodology [4, 5, 6, and 7]



Grid Ruler, Mechanical Pencil, Paper

Columns, Sign, Steps

Figure 2: Example Monomorphs

Transformers Methodology

The measurable value of methodologies for expanding design creativity is well demonstrated in the literature [1, 2, and 4 through 14]. Since the use of methodologies remains emergent, there is much room for expansion and fundamental research. One such avenue to pursue is towards a technique for identifying which design problems are suited to transformable design solutions. Our previous work has seen the development of a technical design method, which proposes a response to the question: “When should a designer or design team pursue the design methods associated with developing a transformer?” Our novel method identifies, at an early stage in the design process, when developing a transformable product is likely to be advantageous [1]. Both deductive and inductive studies were used to identify transformation indicators (TI) and monomorph indicators (MI). Respectively, these indicators identify when to create a transformer or a monomorph product, or when to consider both approaches in parallel. An Indicator, herein, is an *identifiable group of characteristic context properties and usage factors.* Figure 3 represents the influence of this method on the design process.

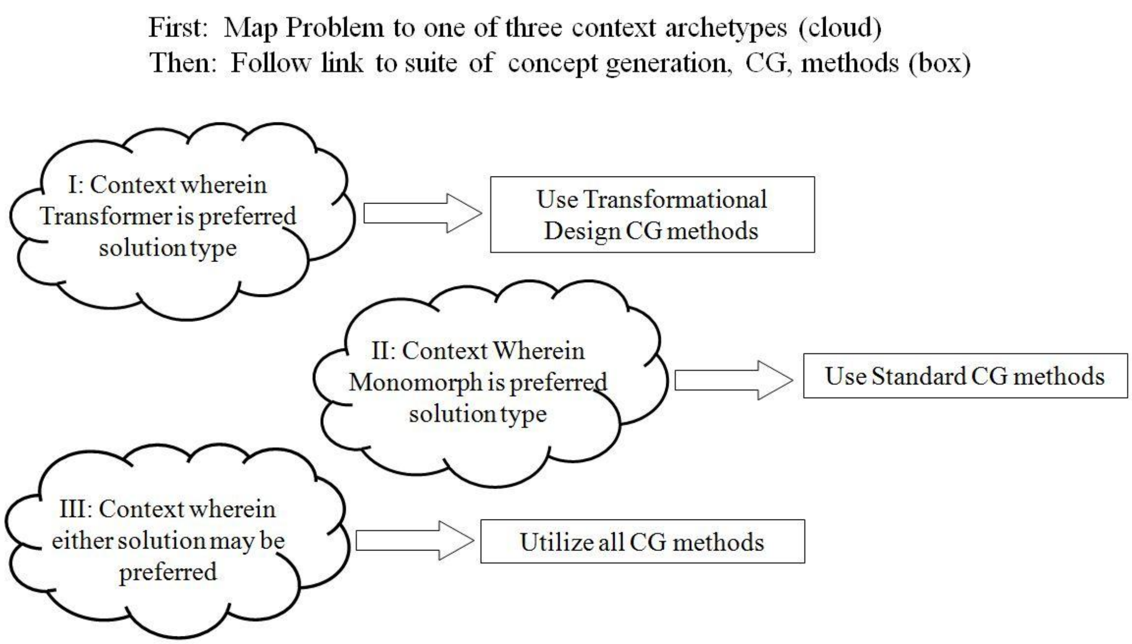


Figure 3: How to Apply the Indicators for Selecting a Concept Generation Tool Suite

Hypothesis and Research Questions

Previous Hypothesis - It is possible to indentify characteristic indicators, *properties of the product usage space, functional requirements, or user needs for a given product design scenario,* which sufficiently classify a design problem into one of two archetypes at an early stage.

This hypothesis has been investigated through analysis and review of two related research questions. The research questions 1 and 2 encapsulate the objectives for the previous study [1]:

Question 1: What context characteristics, or indicators, identify a scenario suitable for the development of a transformable device? (previously reviewed)

Question 2: What context characteristics, or indicators, identify a scenario suitable for the development of a monomorph? (previously reviewed)

Current Hypothesis - **This classification of design context into archetype will be relevant in the sense that, it will most often represent the actual solution form ultimately chosen.** If this second hypothesis is true, it follows that the designer may enhance innovation by concentrating on solution types of that particular archetype. This hypothesis is examined through research question 3:

Question 3: If the indicators are present in a context, how effectively does this indication relate which solution type is preferred? (previously unaddressed)

Overview of Methodology for Research

The over-all research method to answer these three questions involved investigating the context surrounding existing products to determine a set of indicators for when to implement transformable solutions and a set for when to pursue monomorphs. For each indicator study, two independent studies were pursued and discussed in previous research [1]: a deductive study to test sets of hypothetical indicators; and an independent inductive study in which a population of product systems are analyzed. Figure 4 shows the research process as executed. Each deductive approach to studying the research questions hypothesizes a set of transformation indicators based on empirical studies of transformer products, patent embodiments, and systems in nature. Conversely, each inductive approach consists of sequences of functional analysis and comparison of successful transformers and monomorphs. The results of the studies are cross compared and simplified into a compact method.

For this paper, the developed compact method is examined through applied design studies. Validation is symbolized in Figure 4 over the yellow background, and corresponds to the third research question above. In previous papers we have examined research questions one and two, this paper represents the culmination of the research plan in Figure 4.

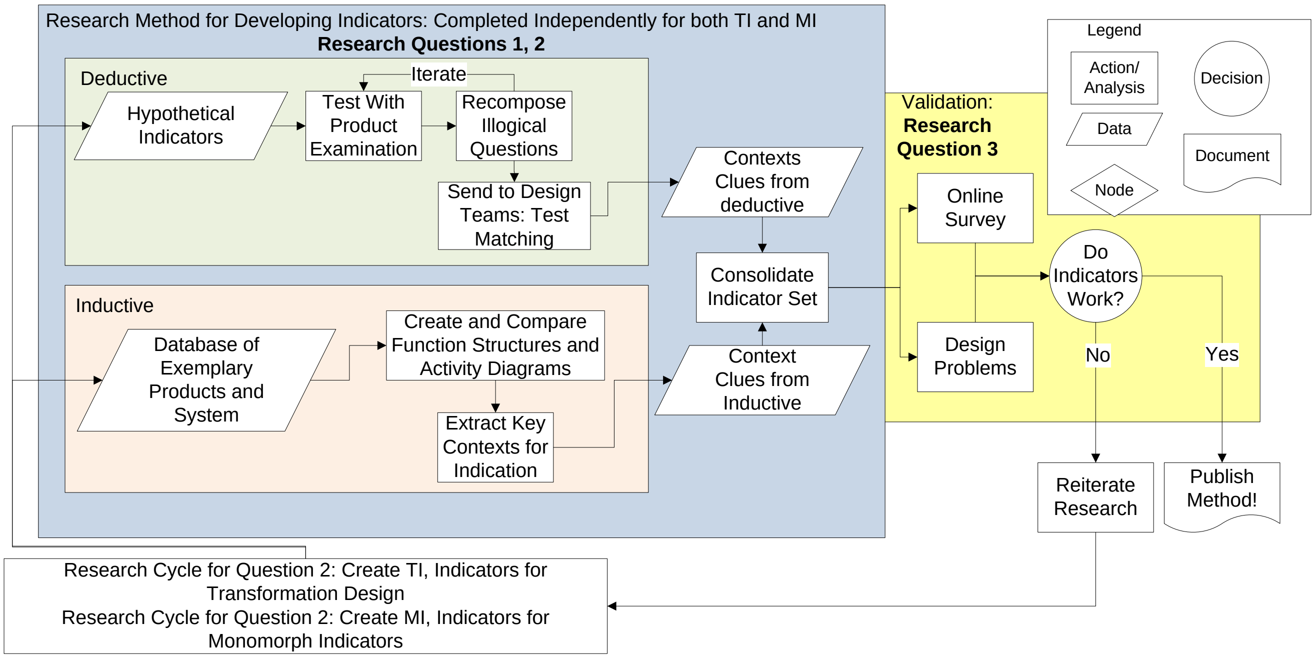


Figure 4: Research Method Flow Diagram

Using Context Indicators: Description of Method

We have previously developed a methodology for determining when to transform [1] which can be seen in Appendix A. The method represents results from the section over blue background in Figure 4. The method is a response to our first hypothesis and presents indicators for transformation. The method consists of three stages as follows:

Stage one - Examine customer needs, usage area and other factors relating to the context of use, as in the typical design process. Primary objectives and functions can be examined in detail.

Stage two - Compare the general context indicators to the specific design context in review. For each indicator (both TI and MI), ask “Does this indicator seem to be descriptive of the particular problem's context?” For this process note that all indicators must be examined and individually compared to the context. A weighted sum of how well each indicator matches will be computed for final prediction. These general context indicators can be found in Appendix A. Some points to consider in conjunction with the descriptions found in Appendix A are summarized in Table 1.

Table 1: Points to Consider During Examination of Context Indicators

Transformation Indicators	
Share Functions	Consider the functions of products used nearby
Adhere to a Variable	Look for sets of devices with similar function, such as measuring cups
Accommodate a Process	Examine the process associated with the device. Also look at activities occurring just before and after use.
Store	Consider what happens to the device when not in use
Monomorph Indicators	
Design for Low Cost	Consider the importance of cost saving
Synchronized Multi Function	Examine the usage process, particularly activities occurring during use.
Conditional Periodicity of Use	Determine the use frequency
Vital Function	Consider the sensitivity of the most critical function to state changes
Limited Instruction	Consider the first interaction of the user and device

Stage three - Develop a quantified degree of matching between indicators and the selected design context using a Likert scale as shown in Figure 5. To do so, first print, then fill in Figure 5. Larger circles are filled in to indicate more relevancy or 'agreement' between the indicator described and the design problem at hand. The largest circle is assigned a point value of '2' and '1' for the second largest circle, all smaller circles receive value '0' since they indicate 'disagreement'. This point evaluation is used to indicate which design archetype is likely to be preferred using the calculations described in Equations 1 and 2. Finally reference Table 2 to determine which concept generation techniques to use.

Equation 1 $$\%TI = \frac{\sum_{i=1}^{N_{TI}} TI_i}{Val_{max} N_{TI}}$$ Equation 2 $$\%MI = \frac{\sum_{i=1}^{N_{MI}} MI_i}{Val_{max} * N_{MI}}$$

In Equations 1, and 2:

$TI_{i,}$ MI_i are respectively the point value assigned by the respondent for the i^{th} transformation and monomorph indicator questions. Val_{max} = 2, i.e., maximum possible point value response of strongest agreement on Likert scale. N_{TI}, N_{MI} are the number of questions relating to transformation indictors and monomorph indicators respectively. %TI or %MI is the strength of indication (between 0 and 100) to pursue that respective archetype.

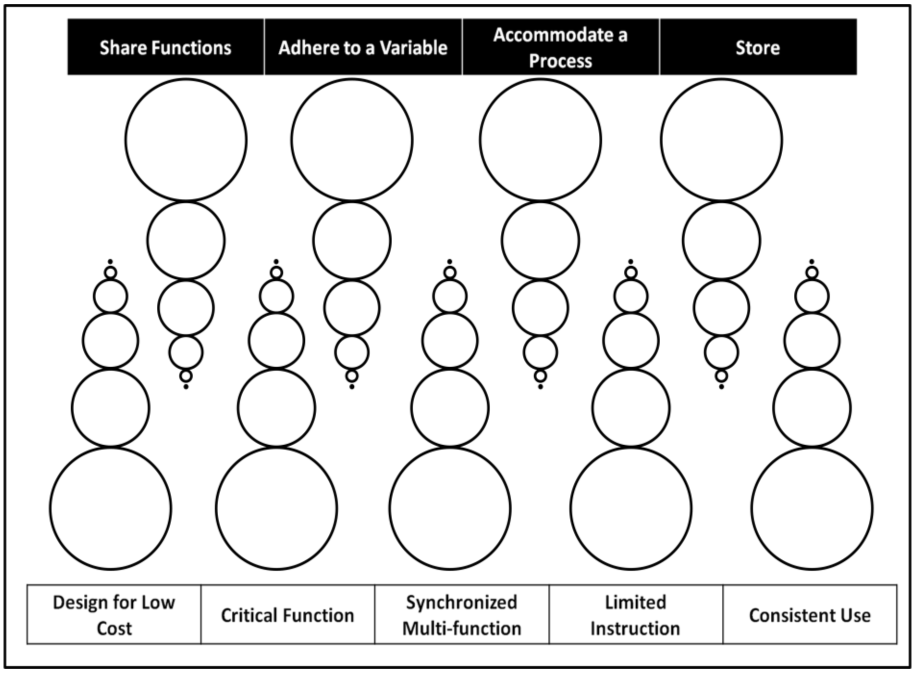


Figure 5 Blank Likert Circle Table

Table 2: Selecting a Methodology

Percentages of Indicators	Suggested Methods to Pursue
%TI > %MI and (%TI - %MI) > 15 %	Transformers Methodology
%MI > %TI and (%TI - %MI) > 15 %	Monomorph (regular) Methodology
(%MI - %TI) ≤ 20%	Both Transformers and Static Function State Methods

Description of Experiment to Address Research Question 3

The indicators for transformation are experimentally determined and composed into a survey-like method in our previous research, Appendix A. For this experiment, the survey method in Appendix A is given to six design teams (four of which completed the exercise fully) at a higher education institution. The teams of designers applied the method to their specific design problem and then returned the results. Each team member individually applied the method without collaboration with other team members. The method consists of a sequence of Likert scale questions. The questions each relate to one of nine indicators. Five which indicate a general form of design scenario where monomorphs are preferred and four corresponding to transformable design preference. When the applicant agrees that their method is like those archetypical to a transformable solution, the method suggests pursuing a transformable concept and vice versa for indication of monomorphic context archetype. The method simplifies this level of agreement into a single number, permitting quantification of a qualitative understanding. The teams applying this survey each had unique problems and consisted of more than forty senior mechanical engineering students at a higher educational institution.

Analysis Used on Experimental Data

As described above, two results are gathered from the experiment. These results are the similarity of description between teams and a validation of the indication method. A positive result from these two data sets indicates that the teams have a general agreement on what problem is being solved and then when this method is applied to a problem description at the early stage, it correctly identifies what is likely to be the designers preference for either transformable or monomorphic design. The methods for calculating each of these results are described in detail.

Validation of the method's efficacy to indicate a preference for transformation of monomorphic design has been evaluated for our design teams. Teams of student designers investigate context surrounding their design problem with the survey, Appendix A. The survey asks, "Is an indication for transformable or monomorphic solution present in contexts surrounding the design problem?", indirectly through description of the indicators. Answers to this question are compared with subsequent (later in the semester) team decisions for product archetype, this is the first experimental result. The survey results in a single percentage evaluating the indication for preference of a transformer or monomorph design. Example: the context would strongly indicate a need for transformation if TI (transformation indication percent) = 60% and MI (monomorph indication percent) = 10%, since TI >> MI. This scoring is evaluated only in cases where the difference is greater than 15% since that is the system minimum resolution. This indication is compared to the actual design decision towards transformer or monomorph to establish validation. Validation is computed using Equation 3.

Equation 3

$$\begin{gathered} if\ \%TI \gg \%MI\ and\ FORM(solution) = T\ or \\ if\ \%TI \gg \%MI\ and\ FORM(\ solution) = M; \\ 1\ is\ added\ to\ validation\ score \end{gathered}$$

In Equation 3:

Possible values of 'FORM' are T and M, corresponding to whether a transformer and monomorph design solution was selected for prototyping. Thus if the method worked perfectly, the number of validations should equal the number of applications of the method. If the statements are false, then a value of '0' is added to validation

Similarity with which team members describe their problem is examined also. The second analysis of survey results measures the intra-team agreement in description of the problem statement. Each team member individually listed the five most important product functions. If each team member lists five different functions from each other member, similarity is at a minimum, if each team member lists the same five functions, similarity is at a maximum. For each team the similarity of responses is measured.

$$if\ LENGTH(A) = 3,$$

Equation 4

$$S = \frac{SIZE(A_1 \cap A_2) + SIZE(A_1 \cap A_2) + SIZE(A_2 \cap A_3)}{LENGTH(A) * SIZE(A_1)}$$

In Equation 4

'LENGTH()' returns the number of team members in team A. 'S' is the similarity fraction. '$SIZE(A_1 \cap A_2)$' compares each element from the lists A_1, A_2, and returns the number of shared elements. Thus, if there were three team members in group A; defined as A = [A_1, A_2, A_3], where each list A_i is the response from an individual on that team (example: A_1 = ['perch', 'survey', 'rechargeable', 'takeoff', 'return']). If the respondent A_1 included the same functions as respondent A_2 then, SIZE($A_1 \cap A_2$) = 5, if only two listed functions were the same then SIZE($A_1 \cap A_2$) = 2.

Results, Discussion, and Conclusions

The experimental results are twofold: similarity of problem description of individuals on a team and effectiveness of the method to predict solution form. The first result, similarity of description shows that teams generally describe problems in the same way. Additionally this method could assist discordant teams in development of a hierarchical list of objectives. The computed results are list in Table 3, the list of specific responses is included in Appendix B.

Energy Harvester	60%
Micro Aerial Vehicle	43%
Tunneling Robot	80%
Personal Transporter	80%

Table 3: Similarity values of four teams, expressed as a percentage (S*100%)

The analysis summarized in Table 3 examines team member to team member consistency in describing the five primary functions for that project. Since one of the teams shows a vastly lower value than the others, it may be of interest to comparatively examine their design problem. The MAV team has a problem which consists of many performance stages when compared to the others. The device is required to deploy on site, travel to location, perform surveillance, reorient if needed, take-off and return to base having performed each operation stealthily. In comparison the other teams may only have two or three objectives. The project directives also each come from different sponsors. The MAV project comes from a sponsor interested in proofs of concept. Finally the MAV project is an older project, thus previous semesters insights may influence project definition.

The validation study compares the survey results, indication for transformer or monomorph with the chosen design form. As alluded to in Equation 3, the method is validated when the outcome, chosen design, matches the prediction, indication (TI or MI). The outcome is compared to the prediction. The method was applied on each of the five functions by each team member. There were a total of fifty three applications. The ratio of correct indications to incorrect indications is 34 to 10. A more detailed list of the results can be seen in Appendix B. Table 4 also shows an examination of the appearance of transformable and monomorphic concepts found in the Pugh charts of concepts for each team. The most interesting result may be the personal transporter system. The transporter survey demonstrates a relation between a mix of transformation and monomorph indication, and a corresponding mix of monomorphic and transformable aspects in their selected design. Additionally one of the M.A.V. concepts can be seen in Figure 6, which depicts a transformer wing-parachute design.

Team	# Transformer Concepts	# Monomorph Concepts	Selected Concept:	Method Indicated
Energy Harvester	0	**12**	Monomorph	Monomorph
M. A. V.	**20**	10	Transformer	Transformer
Tunneling Robot	**10**	0	Transformer	Transformer
Personal Transporter	**3**	**6**	Transforming subsystem, mono-morph over-all	MI - 6 BOTH - 6 TI - 3

Table 4: Detailed Analysis of Team Responses

The key findings of the research are that individuals on teams tend to describe their problem in a similar way and that the indicators method is effective at predicting preferred archetype. Limitations of the research methodologies stem from the sample size used. For instance, if the research were applied over several semesters at several different schools, we would hope to find the same results however it is possible that many new insights would be developed.

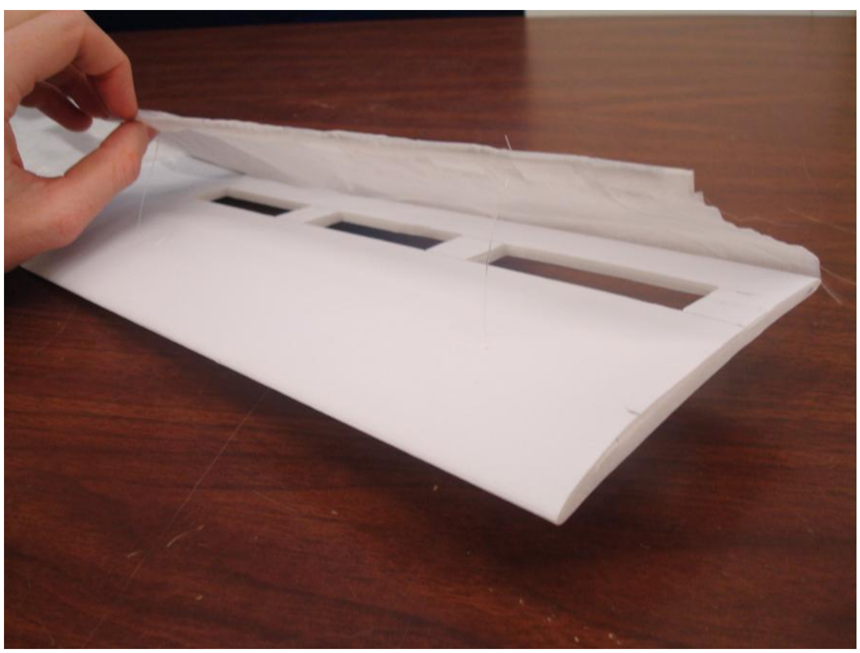


Figure 6: Depiction of Wing-parachute Transformer

As per the results of this research, the method is effective at providing a general conclusion as to what design archetype will be preferred given a design problem. Thus in the future, applicants of the method can apply the method and directly move to concept generation of that form. Each of the teams surveyed has begun prototyping their design and finds their choice to be satisfactory. The method encourages designers to consider a solution form, transformable, that they previously may not have. Additionally this consideration may be able help a team to arrive at a preferable solution in a shorter length of time by using the method to quantify preference for transformable or monomorphic solutions.

Future Work

Our Future work to expand this research would include refinement of the methodology. One additional line on the survey allowed comments. Most students wanted to spend more time considering what is meant by context in this sense. To refine the method we may include a broader introductory example problem which explains 'context surrounding a design problem' in future iterations of the methodology. Additionally, we may consider evaluating our intuition that the method will save time, compared to a control who is not applying the methodology. Our hypothesis is that there will be a breaking point, that is for projects with a longer time scale, the method will be most effective.

Acknowledgements

This work is supported in part by a grant from the Air Force Research Laboratories (AFRL/RW at Eglin AFB, FL, ARFL/RB at Wright Patterson AFB, OH and AFRL/RX at Tyndall AFB, FL) and, in part, by The University of Texas at Austin Cockrell School of Engineering and the Cullen Trust Endowed Professorship in Engineering No. 1. In addition, we acknowledge the support of the Department of Engineering Mechanics at the U.S. Air Force Academy. Any opinions, findings, or recommendations are those of the authors and do not necessarily reflect the views of the sponsors.

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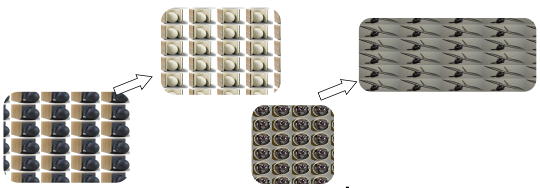
Appendix A

Method/Survey: Determining Preferable Device Archetype

What types of designs are we looking to develop?

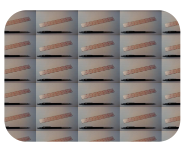
Either: Transformer

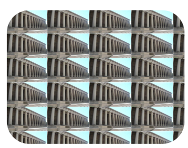
- **Transformers –** ***devices or systems with state reconfiguration for multiple or enhanced functionalities***
- Generated from transformational methods



Monomorph

- **Monomorph –** ***products with one primary functional state***
- Generated from standard ideation





Example Compare the problem statement "Design a device to deploy from FOB and neutralize enemy MAV" with Transformation Indicator 1, seen below

Share Functions
Question Is the product used in a process or environment with devices that share: • Function? • Usage Process? • Physical Architecture?
Action Item Consider the functions of products used nearby

Compare with objectives

Objective A "Deploy Anti-MAV device from storage state"
Choose somewhat agree, there may be other MAV nearby on base, transform between attack MAV and Anti-MAV

Objective B "Neutralize enemy MAV", choose disagree, midflight there are few devices nearby

A	◯	●	○	○	∘	·
B	◯	○	○	○	•	·

Tear Out this Page

- List each principle objective for which concept drawings will be made (n $\geq$ 1)

A	
B	
C	
D	
E	

- Continue the survey
- Respond for each objective uniquely
- The indicators describe a scenario
- Compare that scenario to the objective

Strongly Agree	Agree	Somewhat Agree	Somewhat Disagree	Disagree	Strongly Disagree
◯	○	○	○	∘	·
The indicator applies to the objective very readily					The indicator and objective have nothing in common

Transformation Indicator 1/4

Share Functions
Question Is the product used in a process or environment with devices that share: • Function? • Usage Process? • Physical Architecture?
Action Item Consider the functions of products used nearby

A	◯	○	○	○	∘	·
B	◯	○	○	○	∘	·
C	◯	○	○	○	∘	·
D	◯	○	○	○	∘	·
E	◯	○	○	○	∘	·

Transformation Indicator 3/4

Accommodate a Process
Question Does device usage occur with a process of multiple objectives where steps need not be completed simultaneously?
Action Item Examine the process associated with the device. Also look at activities occurring just before and after use.

A						
B						
C						
D						
E						

Transformation Indicator 2/4

Adhere to a Variable
Question Is there an expected variation in: • Inputs and outputs to the device? • User properties?
Action Item Look for sets of devices with similar function, such as measuring cups

A						
B						
C						
D						
E						

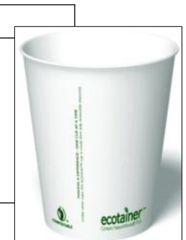
Transformation Indicator 4/4

Store
Question Do any of the following apply to the device: • Frequently moved? • Used infrequently? • Operated in multi-purpose or crowded spaces? • Deployed?
Action Item Consider what happens to the device when not in use

A						
B						
C						
D						
E						

Single State Indicator 1/5

Design for Low Cost
Question Is low cost a major design constraint as exemplified by the following: • Intended for casual use? • Massively distributed? • Frequently replaced?
Action Item Consider the importance of cost saving



A						
B						
C						
D						
E						

Monomorph Indicator 2/5

Synchronized Multi Function

Question
Will usage occur such that multiple objectives must be addressed in parallel?

Action Item
Examine the usage process, particularly activities occurring during use.

A						
B						
C						
D						
E						

Single State Indicator 4/5

Vital Function

Question
Is the design goal overwhelmingly to complete a single objective with:
- Durability?
- High performance?

Action Item
Consider the sensitivity of the most critical function to state changes

A						
B						
C						
D						
E						

Single State Indicator 3/5

Conditional Periodicity of Use

Question
Does the use period require one of the following:
- Continuous use?
- Stochastic use period?

Action Item
Determine the use frequency

A						
B						
C						
D						
E						

Single State Indicator 5/5

Limited Instruction

Question
Does the user have limited instruction for the device as from lack of the following:
- Experience?
- Ability or capacity?
- Interest?

Action Item
Consider the first interaction of the user and device

A						
B						
C						
D						
E						

Evaluate which methods to focus on

Strongly Agree	Agree	Somewhat Agree	Somewhat Disagree	Disagree	Strongly Disagree
5	4	3	2	1	0

- Using the example above, assign a value to each circle
- Next add the total value for the four transformation indicators and the five monomorph indicators, and place as sums below
- At this point you should have two numbers ranging from 0-20 and 0-25 respectively, fill out the tables below to compute the indicator percentages => Then go to the last page

Transformer scenarios 1->4	Monomorph scenarios 1->5
Objective A : (Sum of agreement)/ 0.20 = ___	Objective A : (Sum of agreement)/ 0.25 = ___
B: (Sum of agreement)/ 0.20 = ___	B: (Sum of agreement)/0.25 = ___
C: (Sum of agreement)/ 0.20 = ___	C: (Sum of agreement)/ 0.25 = ___
D: (Sum of agreement)/ 0.20 = ___	D: (Sum of agreement)/ 0.25 = ___
E: (Sum of agreement)/ 0.20 = ___	E: (Sum of agreement)/ 0.20 = ___

Congratulations

- Responses above can be used to determine whether to focus on using transformers methodologies or standard concept generation tools
- Compare the transformation and monomorph indication for each objective
- If the indication value is > 10% towards transformer or monomorph then utilize transformer concept generation methods or standard concept generation, respectively.

Example Usage of Results

If For:
Objective A: Transformation% = 70 Monomorph% = 30%

Then :
Utilize **transformers concept generation tools** for this objective!!

And For:
Objective B : Transformation% = 40 Monomorph% = 90%

Then :
Utilize **standard concept generation tools** for this objective!!

Appendix B

Compilation of Survey Results

Application	Objective	%TI	%MI	Indicates	FORM	plus	minus
Energy1	easy to install	65	52	TI	M		1
Energy1	harvest electricity	70	32	TI	M		1
Energy1	loooks good	65	68	BOTH	M		
Energy1	low cost	60	64	BOTH	M		
Energy1	resist corrosion	65	40	TI	M		1
Energy3	harvest energy	30	48	MI	M	1	
Energy3	durable	5	0	BOTH	M		
Energy3	harvest electricity	30	56	MI	M	1	
Energy3	mount without interference	25	4	TI	M		1
Energy3	non-corrisive	5	0	BOTH	M		
Energy4	resist corrosion	0	0	BOTH	M		
Energy4	last 10 years	0	0	BOTH	M		
Energy4	mounts to bridge, no drilling	0	0	BOTH	M		
Energy4	needs no outside power	70	16	TI	M		1
Energy4	Power sensors anytime	65	16	TI	M		1
Energy5	harvest electricity	50	60	MI	M	1	
Energy5	limit wire usage	0	20	MI	M	1	
Energy5	mount to bridge	0	44	MI	M	1	
Energy5	resist corrosion	0	20	MI	M	1	
Energy5	store energy	70	60	TI	M		1
MAV1	land/relaunch	25	68	MI	T		1
MAV1	High Velocity	55	48	BOTH	T		
MAV1	ISR	30	60	MI	T		1
MAV1	Long Loiter Time	30	60	MI	T		1
MAV1	Low Observability	65	64	BOTH	T		
MAV2	Attach Capabilities	75	28	TI	T	1	
MAV2	Camoflauge	75	28	TI	T	1	
MAV2	harvest electricity	75	40	TI	T	1	
MAV2	ISR	75	40	TI	T	1	
MAV2	Perchin	80	48	TI	T	1	
MAV3	harvest electricity	60	56	BOTH	T		
MAV3	land	60	64	BOTH	T		
MAV3	move	55	60	BOTH	T		
MAV3	re-launch	60	64	BOTH	T		
MAV3	survey/recon	55	60	BOTH	T		
MAV4	isr capable	65	36	TI	T	1	
MAV4	loiter time	60	44	TI	T	1	
MAV4	quite to site	60	32	TI	T	1	

Application	Objective	%TI	%MI	Indicates	FORM	plus	minus
MAV4	relaunch	80	28	TI	T	1	
MAV4	weight-size	80	60	TI	T	1	
Robo1	clear 2ft obstacle	60	40	TI	T	1	
Robo1	fit 8in hole	65	40	TI	T	1	
Robo1	navigate rough ter	50	40	TI	T	1	
Robo1	pass chasm	60	40	TI	T	1	
Robo1	payload	65	40	TI	T	1	
Robo2	8" hole	40	20	TI	T	1	
Robo2	chasm	40	20	TI	T	1	
Robo2	rough terrain	70	20	TI	T	1	
Robo2	step	40	20	TI	T	1	
Robo2	travel quickly	70	20	TI	T	1	
Robo4	1400ft tunnel	55	48	BOTH	T		
Robo4	2ft chasm	55	48	BOTH	T		
Robo4	2ft step	55	48	BOTH	T		
Robo4	8in hole	55	48	BOTH	T		
Robo4	navigate rough terrain	55	48	BOTH	T		
Robo5	climb a 2ft step	45	48	BOTH	T		
Robo5	deploy 8in hole	45	40	BOTH	T		
Robo5	navigate a 2ft chasm	45	48	BOTH	T		
Robo5	navigate rough terrain	55	40	TI	T	1	
Robo5	navigate water	55	40	TI	T	1	
SAC1	carry load	60	64	BOTH	B	1	
SAC1	durability	35	60	MI	B		
SAC1	quiet	30	64	MI	B		
SAC1	rough terrain	80	56	TI	B		
SAC1	speed	75	68	BOTH	B	1	
SAC2	carry load	70	44	TI	B		
SAC2	climb steep angles	40	48	BOTH	B	1	
SAC2	move accross rough terrain	35	48	MI	B		
SAC2	move quickly	65	48	TI	B		
SAC2	quiet	30	40	MI	B		
SAC3	quiet	80	80	BOTH	B	1	
SAC3	range	25	48	MI	B		
SAC3	speed	25	44	MI	B		
SAC3	strength	40	44	BOTH	B	1	
SAC3	terrain	55	56	BOTH	B	1	