



The Design Journal An International Journal for All Aspects of Design

ISSN: 1460-6925 (Print) 1756-3062 (Online) Journal homepage: http://www.tandfonline.com/loi/rfdj20

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**To cite this article:** Philippa Mothersill & V. Michael Bove Jr. (2017) Humans, Machines and the Design Process. Exploring the Role of Computation in the Early Phases of Creation, The Design Journal, 20:sup1, S3899-S3913, DOI: <u>10.1080/14606925.2017.1352892</u>

To link to this article: <u>http://dx.doi.org/10.1080/14606925.2017.1352892</u>

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12th EAD Conference Sapienza University of Rome 12-14 April 2017

# Humans, Machines and the Design Process. Exploring the Role of Computation in the Early Phases of Creation

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**DESIGN FOR NEXT** 

EAD12-ROME

doi: 10.1080/14606925.2017.1352892

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**Abstract:** Computational tools and the methodologies used in the early phases of creation often have conflicting requirements related to structure and systematicity. This paper describes an exploration into the increasing role that computation could play in the early stage of the design process. Insights from case studies at the design consultancy IDEO identified several key design activities and process variables used throughout the projects. Breaking these down into the contributing knowledge and creative 'functions' allowed computational representations to be created and a creative prompt tool developed. Further considerations on the possible features for the next technologies developed for these design activities concluded that a 'bricolage toolbox' of small, flexible and personalisable modules will enable the more ad hoc approach that is present in the early phases of creation.

Keywords: Design process, computational design, creativity support tools

## 1. Introduction

Since the mid-twentieth century, computation has become an increasingly important tool for designers. From the computer-aided machining tools that sought to "replace an individual's embodied engagement... with repeatable and controllable digital process" (Llach, 2015) to the Computer-Aided Design (CAD) tools that parameterised our drawings (Sutherland, 1963) to scientific research into a more computational epistemology of design (Simon, 1996), researchers have been striving to more closely integrate the logic and machinery of computation into the creative process.

Gero (1990) in particular uses language familiar to the computational world when he writes that designing "can be modeled using variables and decisions made about what values should be taken by these variables." Applying this model to computational tools of the past, where automation of design tasks was the key goal, one could say that designers defined both the variables and the values for designs; the computers helped repeat their execution precisely. Today, designers can input key variables of a design into CAD tools that iteratively test huge numbers of different values to quickly output many alternatives with optimal characteristics defined by certain goals (Papanikolaou, 2012).

But how do designers initially define these design variables to assign values to? Are there any overarching categories of variables that guide the design process? What is the role of computation in this early phase of creation and how can it be improved? This paper describes research carried out at the product design consultancy IDEO that investigated these questions and contributes to this growing discussion by presenting a framework of design process variables and a new computational tool in which they may be used.

## 2. Integrating Computation into the Design Process

"[Design] intentions may be very vague at the outset, then may evolve and sharpen as the design process unfolds" (Mitchell, 1993)

"Algorithmic representations require an explicit awareness of underlying assumptions and details" (Stiny & Gips, 1978)

The above quotes highlight the dilemma presented when applying computation to the early stage of the creative process. The automatic generation and optimisation of many new values for design variables by today's computational design tools is possible because an explicitly understood and code-able algorithmic logic has been found that can define equations relating the different variables to each other (Alexander, 1966; Loukissas, 2012; Stiny & Gips, 1978). The early creative process on the other hand is an exploratory cycle of experimentation and evaluation (Schön, 1983) that meanders between phases of discovering variables, reframing concepts, envisioning solutions and creating designs (Mendel, 2012). There are no explicitly definable algorithms for the design yet; the variables are still emerging from considering a range of unexpected alternatives (Mitchell, 1993). Through a process of reflection-in-action, the designer continually tests their early 'hunches' and evaluates the experiments with respect to how well the design variables contribute to the overall reframing of the design problem (Alexander, 1967; Schön, 1983).

To generate truly paradigm-shifting 'creative' designs, this exploration relies on "the introduction of new variables into the design process, variables which were not originally considered by the designer or design system" (Gero, 1990). Such new variables can be found in many ways: reinterpreting the existing design by mutating its features, reframing it by considering analogies several levels of abstraction away from the original context, recombining ideas in surprising new ways to create a new requirement, or from first principles (Gero & Maher, 1993; Minissale, 2013; Schön, 1983).

These discrepancies between the explicit requirements of computational design and the nebulous experimental journey of early creative explorations highlight the challenges when applying computational design tools to this stage of the process. This is presented very clearly in a diagram by Bernal, Haymaker, and Eastman (2015), shown in Figure 1. It maps out the different human and computational tools available for the 'actions' of the design process; from early explorations, where tacit knowledge is used to discover, reframe and define the design variables, to the more explicit envisioning and creation of solutions where values are assigned. Fewer darker squares are present in the early activities of the design process indicating a lack of computational tools available, which Bernal et al. (2015) posits is due to the fact that the explicitly-defined hierarchical data structures required for computer programs are limited in their ability to support the more heuristic, abstract thought processes and ad hoc methodologies present in the variable definition stage.

This research strives to address these limitations. The following sections describe the academic and field research into understanding the categories of variables used throughout the development of a design, and describe the development of a computational tool that could play a role in this early stage of the creative process.

Expert's actions		Generation						Evaluation		ion	Selection		on	Integration			
	Computational Approaches		Parametric Modeling	Expert Systems	Generative Design	Design Languages	Agent-based	Casa-based Reasoning	Performance Evaluation	Rule Checking	Constraint-based	Utility	Multi-attribute	Optimization	Custom tool integration	Interoperability	MBSE
plicit knowledge	Situation	Reformulating SFB															
		Forming Analogies															
		Looking for Emergence															
	Problem	Framing Design Situation															
		Co-Evolving Problem-Solution															
		Building Under-Determined Problems															
	Patterns	Recalling Chunk of Constraints													0		
		Recalling Conceptual Structures															_
		Recalling Design Schemata				_											
	Solution	Following Parallel Lines of Thought															
		Evaluating Preliminary Solutions	_			_	_										
		Integrating Knowledge															
	Domain	Recalling Recognizable Problems															
		Building Repository of Parts									_						
		Applying Design Rules										_					
ex		Applying Evaluation Methods															
_ human based = computer sided = computer based = computer successful																	
	= numan-based = computer-aided = computer-based = computer-augmented																

Figure 1. Bernal et al. (2015) diagram of human and computational tools available for the 'actions' in the design process

# 3. Researching the Variables in the Design Process

What are the variables that are explored and discovered in the early stage of the design process? Eisenhardt's (1989) methodology to build theories from case studies was used to investigate this question in both the literature and real design projects.

#### 3.1 Review of existing models of the design process

To inform the case study research, 88 existing design process models (Dubberly, 2004) were semantically analysed to identify any correlations in the variables used (Figure 2). Of the many structures and activities present in the models, a set of general design variables did not emerge. However, the words used in the models could be divided into two simple categories:

- Activities: the *processes* that are used to develop the design such as 'identify', 'synthesise' and 'evaluate', and often refer to the specific *knowledge* and *tools* used, e.g. during the 'rapid prototyping' process, knowledge about different scenarios can be applied to the design and mocked up using a 'videography' tool
- Artefacts: the conceptual or physical design components created throughout the process, such as 'specifications', 'concepts' and 'models', and act as *inputs* to and *outputs* from a design activity, e.g. a list of 'essential problems' can be used as an input to a brainstorming process that outputs a range of 'conceptual variants'

This framework allowed most of the design process models to be analysed using these categories the processes, knowledge, and tools used during the activities, and the input and output artefacts created—and was used to guide the collection of information during field research of real design projects at a design consultancy.



Figure 2. A segment from the semantic analysis of Pahl and Beitz's 1984 design process model included in Dubberly's collection ('activities' highlighted in green, 'artefacts' in yellow)

### 3.2 Field research at IDEO design consultancy

The above framework was used to study four product design projects carried out by the Cambridge (MA) studio of product design consultancy IDEO during a six-week research residency in 2016. The case studies selected were current or recent projects that included a range of design outputs (research-inspired concepts, physical objects, digital communications websites and apps). These were chosen to understand the variables used across a range of design disciplines and to provide insights from seeing the projects develop in real-time.

The research methodology for these case studies was guided by semi-structured interviews and ad hoc discussions with twelve designers (eight male, four female) from a range of disciplines - four industrial designers, one interaction designer, one communications designer, two design researchers, two design engineers, one business designer, and one developer. At least two designers of different disciplines were interviewed for each project, allowing a multi-faceted view into each case study.

Participants were asked to discuss the development of the projects they worked on from initiation to final deliverable. Interviews were relatively free form to allow the designers to describe their own interpretation of the design process, but also included questions to prompt discussion around the framework categories, such as: 'What design artefacts, e.g. word maps, images, models, etc. were made throughout the process?', 'What was an input question or idea for a particular stage of the process and what output artefacts did it lead to?'. Questions about the design activities they used

for their discipline were also asked, including: 'What processes did they use during the different design activities?' and 'What knowledge or tools, e.g. CAD software or prototyping media, did they need to achieve this?' The design artefacts that were created throughout the projects, e.g. design research videos, mood board images that led to early concept designs, physical form prototypes that led to design principles, etc. were also reviewed with the participants and their purpose in the design activities discussed.

# 4. Identifying the Variables in the Design Process

Using the 'activities' and 'artefacts' framework to guide the collection of information during the case studies allowed the often ad hoc design processes to be considered in a more structured way. This section describes the resulting breakdowns of the design activities studied and identifies further sub-categories of design process 'variables' used throughout the projects.

#### 4.1 Breaking Down the Design Process

Figures 3 and 4 show two of the four maps created to visualise the breakdown of the case studies. Project specific information has been removed for IDEO confidentiality purposes. Data gathered from interviews and design materials has been represented using the categories of the framework: *input artefacts*, e.g. 'extreme design themes', leading to *output artefacts*, e.g. 'extreme concept mood boards', using design *knowledge*, e.g. 'design elements appropriate for the project context', with specific *processes* or *tools*, e.g. 'image search tool such as Pinterest'. Interpreting the designers interview responses, the knowledge used in the design activities was further broken down using Veneselaar's (1987) model of the four types of design knowledge (Ahmed, 2005)—declarative (or factual), procedural, situational and strategic (or implicit).

These maps reveal that the projects followed the oft described experimental cycle of concurrent analysis, design, and evaluation (Lawson, 2006; Schön, 1983). However, the phases were often very overlapping during early exploration and experimentation activities and so dependent on the project brief and discipline of the designers involved that a generalisable process could not be realistically modeled, e.g. the very large multi-disciplinary project shown in Figure 3 included an extensive design research phase that the smaller more industrial design-focused project in Figure 4 did not. The ad hoc approach to selection of activities in this early phase agrees with Minissale's (2013) posit that the designer's process is one of "making-do with materials—a bricolage—rather than an inflexible systematicity." A comment from one design researcher described this diverse multi-disciplinary exploration method well: *"Design right from the beginning, in whatever medium is most natural"*.

Despite this lack of a generalisable overall process, many of the design activities—such as 'metaphorical inspiration' or 'extreme themes'—were present across all projects. The use of certain knowledge and tools also appeared to be general across projects, with qualitative strategic knowledge used earlier in the design process and the more computational procedural knowledge towards the latter stages, concurring with previous research (Gero, 1990).

A	rtefacts		Activities							
Inputs	Outputs		Knowledge	Process/Tools						
Initial research — questions: 'Hunches' for themes, users, early concepts _ inspired by project brief/topic to guide design research	Design research guide: Profiles of interview participants, discussion themes and sacrificial concepts match/contrast to hunches		<ul> <li>Situational &amp; procedural knowledge on archetypical design themes and design research methodologies</li> </ul>	<ul> <li>Analysis of assumptions/trends related to project context</li> </ul>						
	<b>Consumer prototyping:</b> Selecting existing objects with similar/contrasting elements to possible final artefacts to provoke discussion, e.g. same size, posture, ergonomics	H,	<ul> <li>Strategic knowledge of the design logic and vocabulary of existing design artifacts</li> </ul>	<ul> <li>Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'</li> </ul>						
Metaphorical inspiration: Studio-based and real- world immersion research into designs and experiences analogous to the project context and design archetypes	<ul> <li>Conceptually similar alternatives and design elements:</li> <li>Semantic, visual and tactile descriptions of analogous experiences, artifacts and interactions</li> </ul>	Exploration	<ul> <li>Declarative and situational knowledge on general design outcomes and on relationship of design attributes to contextual experiences</li> <li>Declarative knowledge on ergonomics</li> <li>Strategic knowledge of the design logic and vocabulary of existing designs</li> </ul>	<ul> <li>Observation &amp; photography</li> <li>Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'</li> <li>Internet search for metaphors that reframe verbal/visual design elements</li> </ul>						
Interviews and observations: Interviews/observing users behaviour & interacting with consumer prototypes	Key insights and tensions: Semantic descriptions from metaphorical experiences and interviews referring to design areas of experience, artifact & interaction	Reframing	<ul> <li>Analysis of research to identify extreme words related to contextual experience for general design themes and areas (strategic knowledge)</li> </ul>	- Synonym/antonym finder						
Extreme design elements: Adjectives associated to design elements inspired by the insights and tensions	Extreme design element moodboards: Words & images of existing artifacts, experiences and technologies related to insights & tensions, grouping by general design element	hesis	<ul> <li>Declarative knowledge on general design elements - form, colour, patterning, material</li> <li>Strategic knowledge of design logic and vocabulary of existing design artifacts</li> <li>Declarative &amp; strategic knowledge on design elements relationship to experiential meaning</li> </ul>	- Pinterest and Google image search						
Technology – constraints: Design limitations from ergonomic, cost, manufacturing, etc	Engineering design principles: Approaches for technology, material, manufacturing, modeling to enhance designs considering limitations	Synt	<ul> <li>Declarative &amp; situational knowledge on design engineering elements based on product context</li> <li>Strategic &amp; procedural knowledge for apply design elements within limits</li> </ul>	<ul> <li>Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'</li> </ul>						
Opportunity areas & extreme themes: Title and adjectives of ~3 design themes, e.g. Protection, orientation	<ul> <li>Extreme concept moodboards:</li> <li>Words &amp; images of existing artifacts, experiences and technologies related to extreme theme words</li> </ul>	Envision	<ul> <li>Semantic analysis to break-down and reframe theme into metaphors (procedural knowledge)</li> <li>Situational knowledge of contextual design elements to refine image search</li> </ul>	- Pinterest and Google image search						
<b>Design principles:</b> Adjectives associated to design elements inspired by the extreme themes and relative importance to each design discipline	<ul> <li>Design discipline moodboards:</li> <li>Words &amp; images of existing artifacts, experiences and technologies related to extreme themes &amp; design elements, considering disciplines e.g. ID, interaction</li> </ul>		<ul> <li>Declarative knowledge on general design elements - form, colour, patterning, material</li> <li>Strategic knowledge of design logic and vocabulary of existing design artifacts</li> <li>Declarative &amp; strategic knowledge on design elements relationship to experiential meaning</li> </ul>	- Pinterest and Google image search						
Feedback —	Preferred design principles	ting		- Discussion & visual/verbal analysis						
Extreme designs: Application of chosen design themes and elements to product	Extreme design moodboards: Words and images of new design experiments	Evalua reating	<ul> <li>Procedural knowledge to apply design principles to general forms for the new artefacts</li> </ul>	<ul> <li>Ballpark dimensions of final artefacts</li> <li>3D models (CAD software, e.g. Rhino)</li> <li>Form studies (foam, card, 3D printed)</li> <li>Colour &amp; pattern experiments (physical/digital)</li> </ul>						
Feedback —	Preferred design principles	G		- Discussion and technical evaluation						
<b>Refined designs:</b> – Detailed designs created	Final design principles: Verbal, formal, visual, tactile design principles defined to guide creation		<ul> <li>Procedural knowledge to define form logic</li> </ul>	<ul> <li>Technical requirements &amp; layout</li> <li>3D models (CAD software, e.g. Rhino)</li> <li>Colour &amp; pattern palattes (Adobe software)</li> </ul>						

Figure 3. Map of the activities and artefacts used in one of the most extensive case study projects analysed

	tefacts		Activ	/ities
Inputs	Outputs	- H	Knowledge	Process/Tools
Design archetypes: 'Hunches' for big themes that guide overall experience of the final artifact, e.g. 'natural', 'functional'	Approaches to design: Adjectives and images that describe the specific archetypes most relevant for each of the design elements, e.g. visual, tactile, interactive, spatial etc	'Hunches'	<ul> <li>Declarative and situational knowledge on archetypical design themes and their specific application to design elements</li> </ul>	- Pinterest and Google image search
Contextual inspiration: Relating design elements of the brief, e.g. medical product, to design archetypes	Analysis of existing designs: Semantic, visual and formal analysis of existing experiences & artifacts related to context & design archetypes	oration	<ul> <li>Breakdown &amp; reinterpret existing experiences &amp; artifacts i.e. 'teardown'</li> <li>Strategic knowledge of design logic &amp; vocabulary of existing artifacts</li> </ul>	<ul> <li>Initial technical layout to estimate overall scale</li> </ul>
Metaphorical inspiration: Studio & real-world immersion research into analogous designs & experiences	Conceptually similar alternatives & design elements: Semantic, visual and tactile descriptions of analogous experiences, artifacts and interactions	Expl	<ul> <li>Declarative &amp; situational knowledge on general design outcomes &amp; relationship of design attributes to contextual experiences</li> <li>Declarative knowledge on ergonomics</li> <li>Strategic knowledge of design logic &amp; vocabulary of existing artifacts</li> </ul>	<ul> <li>Internet search for metaphors that reframe verbal &amp; visual design elements</li> <li>Observation &amp; photography</li> <li>Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'</li> </ul>
	<b>Tensions:</b> Semantic axes from contextual & metaphorical experiences referring to design areas: experience, artifact, interaction	Reframing	<ul> <li>Analysis of research to identify extreme words related to contextual experience for general design themes and areas (strategic knowledge)</li> </ul>	- Synonym/antonym finder
Extreme themes: Title and adjectives of ~3 design themes at tension extremes, e.g. Catwalk: Elegant, Bold	Extreme concept moodboards: Words and images of existing artifacts, experiences & technologies related to extreme theme words	Synthesis	<ul> <li>Semantic analysis to break-down and reframe theme into metaphors (procedural knowledge)</li> <li>Situational knowledge of contextual design elements to refine image search</li> </ul>	- Pinterest and Google image search
Extreme design elements: Adjectives associated to design elements inspired by the extreme themes	Extreme design element moodboards: Words and images of existing artifacts, experiences and technologies related to the extreme themes, grouping by general design element	Envisioning	<ul> <li>Declarative knowledge on general design elements - form, colour, patterning, material</li> <li>Strategic knowledge of design logic &amp; vocabulary of existing artifacts</li> <li>Declarative &amp; strategic knowledge on design elements relationship to experiential meaning</li> </ul>	- Pinterest and Google image search
Feedback	Preferred design themes			- Discussion & visual/verbal analysis
Extreme designs: Application of chosen design themes and elements to product	Extreme design moodboards: Words and images of new design experiments	Evaluatin <u>ç</u> 1g	<ul> <li>Procedural knowledge to recombine extreme themes and design elements and apply them to general forms for the new artifact</li> </ul>	<ul> <li>Ballpark dimensions of final artifact</li> <li>3D models (CAD software, e.g. Rhino)</li> <li>Form studies (foam, card, 3D printed)</li> <li>Colour &amp; pattern experiments (physical/digital)</li> </ul>
Feedback	Preferred design principles	reatir		- Discussion and technical evaluation
Refined designs: Detailed designs created	Final design principles: Verbal, formal, visual, tactile design principles defined to guide creation	ι Ο	<ul> <li>Procedural knowledge to define form logic</li> </ul>	<ul> <li>Technical requirements &amp; layout</li> <li>3D models (CAD software, e.g. Rhino)</li> <li>Colour &amp; pattern palattes (Adobe software)</li> </ul>

Figure 4. Map of the activities and artefacts used in another case study with less design research

#### 4.2 The Variables of the Design Process

Despite no coherent overall process model being identified, the above analysis of the activities carried out and artefacts created revealed several similar sub-categories—or design process 'variables'—that the designers applied to specific project information in order to guide their experiments. As one of the industrial designers described: *"Every designer has their 'moves' that they work through to test out ideas"*.

These variables are:

- Artefact types: When considering 'metaphorical inspiration' or carrying out 'consumer prototyping', the designers considered the many different types of artefacts that could be related to their final designs, ranging from objects, images, services, etc. depending on the openness of the brief and the designer's discipline.
- Inspiration sources: There were many sources that inspired the designers while carrying out 'interviews and observations', considering the 'key insights and tensions', and creating 'extreme design elements', ranging from a word mentioned in a design research interview, or experiential elements from an immersive field trip, or a shape or pattern that fascinated them.
- **Experience adjectives:** The designers often used expressive adjectives to describe the experiences they wanted their designs to evoke while semantically exploring the 'key insights and tensions' and creating the 'extreme themes'. These adjectives are layered with meaning and can relate directly to the design attributes of the image or object or be as abstract as the feelings evoked by a brand.
- **Design attributes:** While creating 'design principles' and prototypes of their creations, the designers used their knowledge of 'archetypical design elements' and 'design logic' to experiment with many different attributes that could be relevant to the final product, e.g. the patterns of shapes to create image, or the forms and materials that build an object, or the touch-points that constitute a brand experience.
- **Media types:** The designers experimented with different media types during 'existing artefact teardowns' and when creating 'extreme design mood boards' or early prototypes. They often had their 'go-to's', but mixing it up—using code instead of paint, or vice versa—often helped them to find new inspiration for their designs.

These design process activities, artefacts and variables that emerged from the case study research were used by the author as an initial prompt to consider how these more explicit elements of the design process might inspire the development of new computationally-driven creativity tools.

# 5. Experiments into Computerising the Design Process

#### 5.1 Computational analogies for activities in the design process

The framework and variables described above allowed the ad hoc activities of the early design process to be broken down into a more explicitly defined logic. This section considers how this almost computational understanding of the design process could be used to develop future design tools by actually 'codifying' these logical design procedures. Figure 5 shows an example of this by 'translating' the four types of design knowledge used in the design activities into example code for data structures. Figure 6 takes this further by considering what computational functions may be analogous to some of the activities in the design process. Here, Gero and Mahler's (1993) model of the modes of discovering new design variables—through reinterpreting, reframing, and recombining elements from existing designs—was used as a framework of 'functions' through which the design knowledge can be transformed.

These examples intend to show that by considering the design process from a more computational point of view we can develop a language for the knowledge and processes of design that can be understood by machines. Using this philosophy, a computational tool that uses the 'recombine' function defined above was developed and is described in the following section.

## 5.2 design(human)design

Recombining existing design elements in unexpected ways to discover new variables is a particularly human skill and enabling computational tools to "trigger unpredictable inferences" is a key area of development identified by Bernal et al. (2015). The IDEO designers confirmed this need as many expressed that *"inspiration comes from random but purposeful inputs"* and they often liked situations that provoked their creativity in surprising ways. These insights led to the development of design(*human*)design, a physical and digital creative prompt tool that uses the 'recombine' function defined in Figure 6 to present designers with a structured but serendipitous selection of design variables to inspire creative design ideas. Inspired by similar tools that use chance and ambiguity as a provocation mechanism such as Dadaist poetry (Gaver & Dunne, 1999) and Eno and Schmidt's (1975) Oblique Strategies, design(*human*)design creates a randomly populated sentence from words relating to the five design process variables discussed above: "Design {an artefact type} inspired by {inspiration sources} that is {experience adjectives} through {design attributes} using {media types}".

# Example of knowledge type from studies

**Computational analogy** 



Figure 5. Computational analogies of knowledge types in the design process

#### Design knowledge and processes used in design activities

Breaking down existing experiences and artifacts i.e. a 'teardown', uses declarative & strategic knowledge of design logic of existing artefacts to REINTERPRET elements of existing designs to change their meaning, e.g. changing the material to change the tactile experience

#### Creating extreme themes and mood boards uses procedural & situational knowledge that connects design elements to the context to **REFRAME** concepts related to design words and images, e.g. design theme 'transparency' could relate semantically to 'clarity' and visually to 'x-ray'

#### Creating extreme designs uses procedural & situational

knowledge that connects extreme themes to design elements and applies them to general forms to **RECOMBINE** extreme themes, images and words into new design e.g. apply form of one theme to pattern and material of another

#### **Computational analogy**



Figure 6. Computational analogies of design activities in the design process (knowledge code examples highlighted)

The physical instantiation of design(*human*)design is a deck of cards for designers to use as a creative game to prompt new design ideas. Designers randomly select a card for each variable from a set of examples, e.g. 'an object' or 'an image' for the artefact design variable etc. and create their design inspired by the sentence constructed (Figure 7). Blank cards are also included for designers to add their own examples. A prototype of the design(*human*)design cards were tested during a one-hour workshop held at IDEO (Figure 8). The designers liked the unexpected provocations created by the random card selection, but sometimes selected specific examples of the variables while allowing randomness in others. They also wanted to create their own variables related to their specific project or discipline.

Building on this feedback that designers wanted to selectively randomise some of the variables and personalise the design variable words, an interactive design(*human*)design website was created at designhumandesign.media.mit.edu (Figure 9). A data structure similar to that described for declarative knowledge in Figure 5 is used to store a list of examples for the five design variables which are then randomised using the 'recombine' function. This design variable example list is stored in an online spreadsheet that can be modified by the designers to reflect words that would be most inspiring, e.g. collected from the design research stage of their project.



Figure 7. design(human)design card deck



Figure 8. Example designs created using the design(human)design card deck prototype



Figure 9. design(human)design website with features described

Initial feedback from designers using the design(*human*)design website to inspire specific projects described it as a fun addition to the design process that would be particularly valuable in promoting expansive lateral thinking and idea generation after a phase of more in-depth research. The artefact type, inspiration source and experience adjective variables especially helped to juxtapose disparate research topics and inspire unexpected design directions, while the design attribute and media type variables were useful at guiding the new ideas to a more focused concept. However, despite the authors providing relevant examples, the designers found it challenging to populate the online design variable list with words that were relevant but not too general or specific from their research. Suggestions for improvements included the addition of unexpected analogical words and images related to the design variables selected, and a methodology and computational tool to help populate and continually modify the design(*human*)design database directly from documents in their research. These features are currently being developed by the authors and further more in-depth user studies conducted in the next few months.

# 5.3 Discussion on considerations for future computational design tools

Breaking down the activities carried out in the early design process enabled a consideration of how computation could play a greater role in the unstructured experiments that lead to the identification of new variables and creative designs. In comparison to the explicitly-defined hierarchical structures required in existing tools, the next technologies developed for this more ad hoc process need to provide a 'bricolage toolbox' of smaller more flexible tools that designers can use as their creative process dictates.

Building on these insights, some considerations for future computational design tools for the early creative phase can be proposed:

- 1. Small and modular: The case studies showed that designers used many different design activities as and when appropriate for their experiments. The lack of a defined structure in this variable definition stage contrasts to the more systematised affordances of most computational design tools. New tools must provide a toolbox of these smaller and modular design tasks that can be used in the ad hoc style suited to the exploratory nature of the early design process.
- 2. Flexible and situated: Definition of the design variables highlighted that, while there are some similarities in the activities and variables considered across design projects, each process is situated related to its unique context and individuals working on it. Tools that designers use must therefore be flexible to integrate the varying information in these different situations, e.g. inputting new design variable examples into the design(human)design database.
- **3.** Clear logic and interaction: Any new information inputted to these situated tools could be provided directly by the designers or collected by another computational tool. Either way, the methodology for collecting the information used by these tools and the logic applied to it to generate prompts must be clear so that the designers can understand their interactions with the tools.
- **4. Personalisable:** During the study, the IDEO designers were also asked to consider the role that increasingly intelligent design software could and should play in the design process. A key insight identified was the role that the designer's personality, individual style, experimental attitude or even just self-confidence plays in the final designs created. How might these tools learn our design idiosyncrasies and influence our interactions with them and resulting creations? As well as being flexible to the context of projects, these future tools need to include features that can adapt to the designer's sensibilities and style.

With these proposed features, the authors hope to contribute to the development of future computationally-inspired tools that can help define unexpected variables and provoke creative designs, as well as influence their continued refinement of the design variables, tool features and overall methodologies through which a computational epistemology can be discovered for the early creative process.

# 6. Conclusion

The role of computation in design is expanding to include more and more of the activities a designer carries out during their process. However, the affordances of current tools require designers to explicitly define design variables and adhere to systematic procedures which conflicts with the more ad hoc tool and methodology selection used in the early stage of the creative process. This paper considered how computation might be integrated into the early stage of the design process more effectively and contributes to this growing area of research by investigating how design activities might be broken down and translated into more computationally-parsable attributes and tools that can use them.

Analysis of existing literature and field research at the design consultancy IDEO identified some key categories of activities, artefacts and design process variables that designers frequently use, e.g. using 'metaphorical inspiration' activities to help identify different 'inspiration source' design

variables. Considering the design process through the framework of these categories allowed it to be broken down into a more explicitly defined logic, from which code snippets were written as examples of an internal representation of the design process for a computational design tool, e.g. conditional functions to execute situational knowledge or randomising recombine functions to link design elements in new ways. The use of this code was demonstrated in the design(*human*)design creative prompt tool, which provided designers with random juxtapositions of words from their own research in order to help them generate new design ideas.

This approach could help to develop computational tools that are more appropriate for the early design process. Key design principles of these future technologies concluded that designing a 'bricolage toolbox' of small, flexible and personalisable modules that can be used as and how the designer needs will enable the more ad hoc approach present in the early phase of creation. Computation could then become as powerful a tool in the abstract variable identification activities of the design process as it is in the more explicit value definition stage.

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**Acknowledgements:** Many thanks to the designers in the Cambridge IDEO studio for participating in the field research and their continued feedback on the development of the design tools.