ANALYSING THE USE OF FOUR CREATIVITY TOOLS IN A CONSTRAINED DESIGN SITUATION

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ABSTRACT

This paper investigates creativity tools and their use within highly constrained design tasks. Previously, a coding scheme was developed to classify design changes as 'Creative Modes of Change'. The coding scheme is used to compare the outcomes from the use of four creative tools (supported design) against unsupported design within a constrained task. The tools showed design space expansion, developing additional concepts to those from the unsupported stage. All four tools stimulated 'Creative Modes of Change', although the type varied depending on their operation. 'Assumption Smashing' and the 'Contradiction Matrix' usually stimulate extra function; 'Analogies' and 'Trends of Evolution' improve design performance. The former two usually produce 'Creative Modes of Change' as opposed to routine. The results show some links between the designer's driving force, mode of change and the design outcome. 'New Requirements' as a driving force tend towards creative change and 'Change in Function'; 'Design Improvement' leads to less creative change and 'Change in Performance'. Hence a link may exist between the designer's driver, the design outcome, and the ideal tool to complete the task.

Keywords: creativity, tools, constrained, design

1 INTRODUCTION

This work is part of a larger project which aims to investigate the nature of creativity and the effectiveness of creativity tools in highly-constrained design tasks. Much work has been done on the development and use of creativity tools for conceptual design and the early stages of design. At later stages, and at sub-systems levels, design activities are subject to more, and more tightly specified, constraints. However, this research is based on the premise that benefits will be experienced by introducing appropriate creativity tools through the entire design process, including stages that include highly-constrained design tasks. The potential for benefits from this kind of research has recently also been highlighted in computational creativity research [1]. At low systems levels and in the later stages of the design process, which are more highly-constrained, creative idea generation activities may be quickly passed over, particularly when a parametric or selection design will suffice.

This paper is based on an empirical study of creativity in a highly-constrained design task. In order to interpret the observations, it was deemed necessary to develop a coding scheme to analyse the outputs from this design activity in more detail; the development of this coding scheme was reported upon in [2], and is summarised here. The purpose of this paper is to build upon this coding scheme and apply it to the results found during the empirical study, with a view to gain insights into the use and selection of creative tools, the types of design change that they are likely to stimulate, and the relationships between the designer's driver, mode of change used and final outcome for the design.

1.1 Modes of Change in Design

Based on informal observations of designers who are particularly creative in highly-constrained design situations, the researchers hypothesized that their design solutions and approaches can be coded using an adapted version of McMahon's Modes of Change [3]. McMahon was looking specifically at design activities that have been labeled as 'normal' design [4] or 'variant/adaptive' design [5], where predominantly incremental changes take place. Although not the same, highly-constrained design tasks – the subject of the work reported here - do share some of the characteristics of normal/adaptive/variant design tasks, such as incremental development of the artifact in order to satisfy all constraints as the design space is explored. McMahon suggested that there are five ways in which a product or process can be changed in order to make an improvement. These are called modes of incremental change in design and comprise: design parameter space exploration; improvement in understanding of design attribute relationships; change in product design specification; modification of the feasible design space; and adoption of a new design principle.

For the work reported here, it was necessary to adapt McMahon's Modes of Change in order to be able to code particularly creative responses in highly-constrained design situations. Table 1 below shows how the adaptations were made. So for example, 'Change in the feasible design space' was adapted to become 'Technology pull' in the coding scheme. In this highly constrained case it was hypothesized that particularly creative changes in the feasible design space would manifest themselves as solutions that pull in/deploy a new/different technology to great benefit. 'Change of specified performance parameter(s)' and 'Change of utility function' are considered as 'not related' to 'highly-constrained design tasks' (the focus of this research) as those changes involve changing those constraints.

Table 1: Adaptations to McMahon's Modes of Change

	Modes of Change (McMahon, 1994)	**Relation to highly-constrained design tasks**	**Creative Modes of Change**
Routine	1. Parameter change **(PC)**	Related	Routine
	2. Improved understanding of design-performance parameter relationships **(IU)**	Related	Routine / analytical
	3. Change in product design specification		
	i. Change of specified performance parameter	Not related	N/A
	ii. Change of utility function	Not related	N/A
Creative	iii. Change of set of functional requirements	Related	(1) – New Auxiliaries **(NA)** (2) – Functional integration of other modules **(FI)**
	4. Feasible design space	Related	(3) – Technology pull **(TP)**
	5. Change of principle	Related	(4) – New designs **(ND)**

From the original modes of incremental change, the first two were not considered to be creative by our definition in the sense they were not changes that were original, appropriate and unobvious [6] and therefore were considered routine. Modes 3i and 3ii did not apply to highly constrained design tasks as the brief, constraints and boundaries of the task were considered fixed and well defined. It was suggested that mode of change 3iii, 'change of function requirements' could manifest itself in two forms of creative mode of change; either in the form of a new auxiliary, or in the integration of other modules (functional integration). Additionally, it was suggested that change of feasible design space could be achieved by technology pull as a creative mode of change, and that a change of design principle would be coded as a new design in terms of a creative mode of change. This coding scheme was tested and modified during the empirical study, presented in a previous paper [2]. The final coding scheme comprising of three separate levels of design change that can be analysed in such an experiment, shown in Figure 1 below. Each level is described in the following subsections.

Level 1: Design Drive			
New requirement	Improved understanding	Technology pull	Design improvement

↓

Level 2: Design Modification					
Parameter change	New auxiliaries	Trimming	Modularisation	Functional integration	New design

↓

Level 3: Design Outcome	
Change in Performance	Change in Function

Figure 1: The three levels of design coding

1.1.1 Design Drive

The coding at this level describes the various types of rationale which can drive the specific design modifications. Design rationale includes 'not only the reasons behind a design decision but also the justification for it, the alternatives considered, the trade-offs evaluated and the argumentation that led to the decision' [7]. These are not obvious by simply looking at the design modifications themselves. Even for the same design modification, the underlying rationale may be different and therefore usually best described by the designer who made the modification.

- 'New Requirement' (NR) - One or more new requirements raised by market, organisation designer or any other party, that require new design ideas to achieve.
- 'Improved Understanding' (IU) of design performance parameter - Through modeling and empiricism engineers benefit from the discovery - or better understanding - of relationships between the design parameters and the performance. This understanding can then go on to drive various design modifications.
- 'Technology Pull' (TP) - The adoption of a novel and appropriate technology or material to expand the design space, which can then in turn drive various design modifications. This may have a direct relationship to performance, such as changing material to reduce weight; or it could lead to more complex relationships. One example observed in recent research was the adoption of a new material coating, which enabled a different spray coating process and eradicated post process machining, producing substantial benefits.
- 'Design Improvement' (DI) - Without adding any new requirement, the rationale of the modification is only to further improve the performance of the system. During the iterations of design ideas, the designer sometimes sees opportunities to set higher targets for the system. This raises the standard for the design ideas without adding any new requirements.

1.1.2 Design modification or 'Mode of Change'

This level of coding defines the ways in which each design idea presented differs with respect to a standard or 'reference' design. In this study, the initial unique design idea presented was compared to a common solution already on the market (therefore considered to be the standard). The subsequent design iterations were coded relative to each one preceding it. The codes presented below are based on the assumption that in highly-constrained design tasks, the designer is usually designing 'elements' (parts) of a sub-system, which perform particular 'functions' for the 'system' (or super-system). The different types of changes that are seen as the design ideas evolve are defined as:

- 'Parameter Change' (PC) - In this change the parameter of an existing design element is modified. However the 'performance - attribute' relationships governing the design are not changed as a parameter is adjusted. Thus changing the 'number of wheels on a car' is not a parameter change, as new 'performance – attribute' relationships are inevitably formed when changing the number of wheels.
- 'New Auxiliaries' (NA) - In this change a new function which was not a part of the system, and is distinct from any other function within the system, is added into the system.
- 'Modularisation' (MD) - In this change the functional requirements of a system are fulfilled by an increased number of sub-systems, parts or features. Suh (1990) [8] for example, advocates decoupling functions such that each function has a single associated part or feature.
- 'Functional Integration' (FI) - In this change any two or more elements within the system are combined into a single element that performs the same function.
- 'New Design' (ND) - In this change an existing function is performed by a new element.
- 'Trimming' (TM) - This change occurs when any element is discarded.

Throughout the paper, these codes are given the collective term 'Modes of Change' (MOC).

1.1.3 Design Outcome

Codes in this section describe the different types of outcome observed for the overall system. These describe changes in the overall function or performance or the final resultant benefits to the system from the creative design modifications.

- Change in Function (CF) – Function is either added to or removed from the system. The function may or may not have been part of the original functional requirements.
- Change in Performance (CP) – The existing system performance is raised or lowered.

1.1.4 The Highly-Constrained Design Task

There are many sources of possible constraint within the design task, such as those described by [9], which help to define the structure of the design problems present. Without this inherent structure it can be very difficult to identify in what areas development is needed, or the direction the design should take. A similar situation has also been shown in more specific relation to creativity within design; through appropriate description of constraints within the design process it is possible to generate additional novelty in the final result [10]. However, it has also been shown that constraints can have a negative influence on the outcome, leading to diminished creativity overall [11]. In order to secure a creative outcome within a design, a balance is needed within the use of constraints, in order to adequately frame the problem and provide direction, without placing limits on the final result [12].

In terms of the task performed for this experiment, the levels of constraint are considered high due to the fact that it is a latter stage change, and that it is an incremental improvement of a previous design. This is not to say that the many other sources of constraint do not have impact, but that the two areas described will play a significant role in increasing the constraint above that which occurs in many design situations. The design task is considered late stage in that it is not fundamental to the primary function of the artifact, and is also at a lower level sub-system in terms of system hierarchy. Accordingly, design would likely not occur during the early, conceptual design stage, instead occurring as an embodiment and detailing task once the fundamental requirements had been satisfied. Hence there are constraints and requirements acting on the design task from a relatively large number of sources, [13], including higher system levels that have already been considered and solved to some degree, all equivalent system levels that directly interface with the design task, and the environment. As an incremental design improvement of a previous product, the artifact must conform to several factors that were decided or implemented during the previous iteration. As example, it must not significantly change the dimensions of any interfacing parts in order to minimise re-design of other components, and must be compatible with the current assembly machinery that was developed for the previous version. As such there are further constraints and requirements present that would not necessarily exist in all design situations.

2 METHODOLOGY

The majority of tasks in the project were carried out by a single researcher (HY) who played both the role of the designer and the researcher. This type of participatory action research [14] approach is common in design research. The seminal engineering design research by Hales (1986) [15] is a good example of this design and self reflection research approach. It is important to note that the designer-researcher must be able to clearly differentiate when he or she is in each mode and must be particularly careful not to allow the researcher's mindset to affect the 'natural design behaviour'. This does of course happen to some degree, but can be reduced by adding some form of triangulation to the method. In the research reported in this paper, additional researchers coded the first round of design and analysis. It is worth noting that the designer-researcher (HY) also had excellent 'switching' discipline and the results are robust as a consequence. In order to further reduce research bias, the methodology prohibited analysis and coding until the design activity had finished.

Table 2: Sequence of events for the experiment

Activity Description	**Researcher ID**	**Role Played (designer-researcher)**
First round of design and analysis, unsupported by creativity tools		
Creative Modes of Change	TJH	researcher
Briefing on the highly-constrained design task	HY	designer
Development of design ideas	HY	designer
Review and iteration of the design ideas	HY TJH	designer
Coding the design ideas using 1st coding scheme	HY	researcher
Assessing the quality of design ideas using company's Criteria Decision (MCDA) table	HY TJH	designer
Inter-observer coding of the design ideas using 1st coding scheme	TJH EAD	researcher

Second round of design, supported by creativity tools		
Development of design ideas – With creativity tools	HY	designer
Coding the design ideas using 2nd coding scheme	HY	researcher
Assessing the Quality of design ideas using the company's MCDA table	HY TJH	designers
Analysis of results	all	researcher

A Logitech digital pen and paper note book was used to convert and store a digital copy of the design sketches and written notes that the designer created though the process; and also contained a column that was used by the researcher to code the design outputs. Almost all of the design outputs were also modeled using computer-aided design (CAD), and it is these representations, which were then presented in sequence with significant descriptive notes, that were formally coded. This coding allowed analysis of the design ideas themselves and the creative tools used to develop them, which is the focus of this paper. The task was to design a bottle insert to provide a 'drizzle' function allowing consumers to easily and cleanly pour oils, condiments and dressings. The task is taken from a project previously conducted in industry, the results of which will be used as a basis for further comparison. Table 2 above describes the sequence of activities that took place in the experiment and highlight the particular roles that the various researchers (referred to as HY, TJH and EAD) played.

During the second round of the experiment the designer chose from four creativity tools, specifically selected for their ability to generate a solution using a variety of the 'Modes of Change' and for their applicability when used by a lone-working individual. The four tools selected were 'Analogies', 'Assumption Smashing', the 'Contradiction Matrix' and the 'Trends of Evolution'. The use of these tools within the design process was based entirely on the designer's intuition – he was able to use one or more on any design at any time. This was in order to make the design environment as unrestricted as possible, leaving all constraints within the design task itself and allowing the tools to work in the situations to which they best apply.

In addition to the described coding, each concept was assessed for quality using the companies own, well developed Multi-Criteria Decision Analysis (MCDA) tool. The purpose of this was to allow further understanding of the separate results the creativity tools may generate, whether some may prove more effective than others, and whether any reasoning behind such changes could be identified.

3 RESULTS

This section describes the results obtained from observing, recording and analyzing the design task above, in terms of concepts generated, the level of notation, the concept quality and tool use.

3.1 Concept Generation

Initially, there are interesting results from looking at both rounds, ignoring the tools that were used. Table 3 shows the occurrences of the 'Modes of Change' both during round 1, and round 2. In each round some concepts were developments of previous versions, although always of concepts from the same round. These developments have been listed as concepts in their own right throughout. At no point were concepts from round 1 taken and developed with creative tools during round 2.

Table 3: Occurrence of modes of change with and without creativity tools

Mode of Change	**Number of Occurrences**	
	Without Tools	**With Tools**
Parameter Change	13	4
Trimming	0	0
New Auxiliaries	7	7
Functional Integration	1	0
Modularisation	2	0
New Design	6	3
Total	**29**	**14**

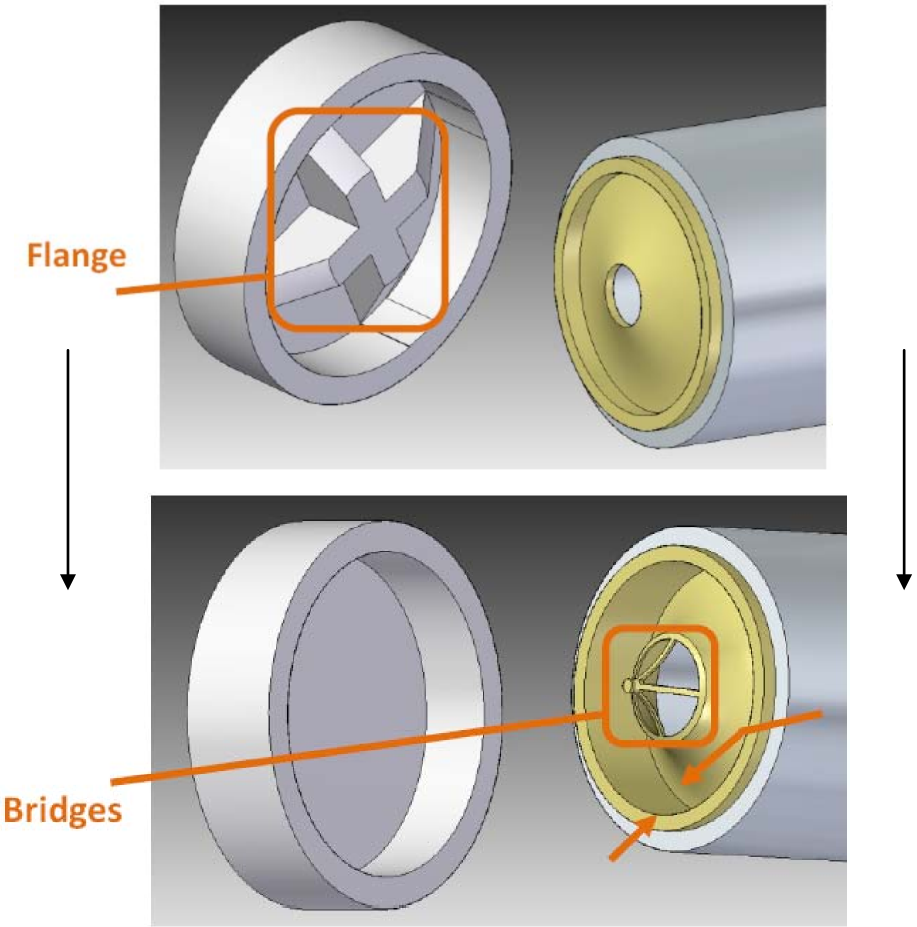

Figure 2: Example of design detail and progression, showing the evolution from an early iteration (above), to a latter version (below)

The above Figure shows the initial stage (left) and result of two developments on an unsupported concept, the first integrating the function of the flange ('Functional Integration') within the lid (shown left in each image) into the bottle insert (shown right). The second development involved an increased depth around the rim of the insert, an example of 'Parameter Change'.

3.2 Levels of Coding

This section focuses on round 2 of the project, looking at the separate levels of coding and the tool use within each.

3.2.1 Middle level of coding, the creative modes of change

The 'Mode of Change' each tool produces give an interesting insight into how each tool may work, and the fundamental benefits that may be gained from specific tool use. Table 4 below shows the number of occurrences of each 'Mode of Change' produced by each tool during the design process, as coded by this designer.

Table 4: Modes of change supported by each creativity tool

Mode of Change	Creative Tool			
	Analogies	Assumption Smashing	Contradiction Matrix	Trends of Evolution
Parameter Change	1	0	0	3
Trimming	0	0	0	0
New Auxiliaries	1	3	4	1
Functional Integration	0	0	0	0
Modularisation	0	0	0	0
New Design	2	1	0	0

Of particular note within this table is the observation that both ‘Assumption Smashing’ and the ‘Contradiction Matrix’ supported only the more creative modes of change, whereas ‘Analogies’ and ‘Trends of Evolution’ showed some tendency towards the routine.

3.2.2 The driving force behind the change

By considering the rationale behind each design change, the tool selected by the designer and the ‘Mode of Change’ that were implemented, some insights into the importance of the initial driving force behind the change can be found. Table 5 shows the driving force as coded according to the method described in Section 1.1 against the ‘Mode of Change’ supported in the middle level of coding. ‘Functional Integration’, ‘Modularisation’ and ‘Trimming’ did not appear during round 2, due mainly to the design task.

Table 5: Tool use categorised by driving force, number of concepts and mode of change

Mode of Change resulting	Number of Concepts (tools used)		
	New Requirement	Design Improvement	Technology Pull
Parameter Change	0	3 (TE x 2, AG)	1 (TE)
New Auxiliaries	5 (AS x 3, CM x 3, AG)	2 (TE, CM)	0
New Design	2 (AG, AS)	1 (AG)	0
Functional Integration	0	0	0
Modularisation	0	0	0
Trimming	0	0	0

Within the table, the initial number shows the quantity of generated concepts, followed by the tools used. As example, when a ‘Design Improvement’ was the driving force two concepts produced ‘New Auxiliaries’, and ‘Trends of Evolution’ and the ‘Contradiction Matrix’ were the tools used.

3.2.3 Bottom level of coding, the outcome of the change

The most interesting results relating to the final outcome of the change become particularly evident when considering them in relation to the initial driving force behind the process.

Table 6: Tool use categorized by driving force, number of concepts and design outcome

Design Outcome	Number of Concepts (tools used)		
	New Requirement	Design Improvement	Technology Pull
Change in Performance	2 (AG x 2, CM)	5 (TE x 2, AG x 2, CM)	1 (TE)
Change in Function	5 (AS x 4, CM x 2)	1 (TE)	0

3.3 Concept quality and tool use

The following shows the quality of each concept along with the tool used to create it in chronological order. In cases where a concept was an iteration of a previous design, only the final and most developed concept was considered, although each of the tools used to generate it is listed.

Table 7: Concept quality and tools used, in order of use

Concept	Quality Score	Creative Tools Used
1	46	Analogies
2	44	Assumption Smashing, Trends of Evolution
3	27	Assumption Smashing
4	26	Analogies
5	38	Analogies, Contradiction Matrix
6	30	Assumption Smashing, Contradiction Matrix, Trends of Evolution
7	35	Contradiction Matrix
8	35	Assumption Smashing, Contradiction Matrix, Trends of Evolution
9	31	Trends of Evolution

4 DISCUSSION

Before discussion of these results, it is first important to point out the limitation that these results are not statistically valid for generalisation across all types of design tasks. However, it is thought that the observations drawn from the results will provide some evidence on which to begin developing creativity tool selection for constrained design tasks. Also, due to the use of a well-developed coding scheme, the results allow the authors to use the case study to draw some conclusions about the creative process, concept generation and the use and selection of creativity tools.

4.1 Discussion of Concept Generation

There are two ways in which the efficacy of creative tools is shown. The high number of designs in the 2nd round shows a significant growth of the design space once tool use began, proving the capability of the tools to stimulate idea generation; and second, all ideas from the 2nd round were genuinely novel in their approach with no discernable influence from the 1st round, hence suggesting that the ideas stemmed from the tools, and were not the result of incubation on ideas developed within round 1. In addition, when looking at the type of 'Mode of Change' supported by the each stage, it is clear that the tools produce a higher proportion relating to those defined as 'more creative' ('Creative Mode of Change'), as opposed to those defined as routine in Section 1.1. In particular, the increase in 'New Auxiliaries' shows that the tools enable the designer to develop new functions at a relatively late stage of the design process due to the expansion of the design space; and the reduction in 'Parameter Change' shows a significant step away from the routine forms of change. It is worth noting however, that as the two stages were a sequential process completed by a single designer, it is impossible to directly compare the results of one to the other as one might in a controlled design environment.

4.2 Levels of Coding

At the middle level, there are two things that are immediately evident. Firstly, each tool is able to produce various modes of change; and secondly, some tools will more consistently produce a more creative type of output than others. 'Analogies' as used by the designer supported a combination of 'New Design', 'Parameter Change' and 'New Auxiliaries'. In this case the analogies were drawn from physical objects, focusing on geometry and structure over process and functionality. This is perhaps why they did not encourage alternative functions that could be incorporated into the task, rather different methods to complete the same task as initially set out. Accordingly, it stands to reason that the overall function of the artifact and its sub-systems usually remained the same; a tool that (in this case) does not focus on function will not yield a change, addition or integration within function at its conclusion. However, if the analogy were to be drawn from a functional perspective (if applicable) there is a chance that the output would contain more examples of 'New Auxiliaries' or 'Functional Integration'. Both 'Assumption Smashing' and the 'Contradiction Matrix' produced a comparable combination of 'New Auxiliaries' and 'New Design', two of the 'Creative Modes of Change', despite the fundamentally different operations. 'Assumption Smashing' removes a logical constraint from the mind of the designer, extending the design space and allowing consideration of previously impossible or unfeasible ideas. The 'Contradiction Matrix' assesses the relationship between two opposed features or functions of a design, and then suggests a method of overcoming the problem. As such it also extends the design space to allow more solutions, but in a far more directed and controlled manner. 'Trends of Evolution' are capable of producing different 'Modes of Change' depending on which aspect of them is used. In this case the designer focused on the mono-bi-poly trend, which then led to parameter change due to the high focus on geometry. However, a structured tool such as 'Trends of Evolution' does have the potential to encourage various 'Modes of Change', depending on which trend is considered, as suggested in Table 8 below. These are examples of the 'Mode of Change' each trend is most likely to lead towards, in reality a combination may apply.

Table 8: The 'Mode of Change' inspired by separate trends of evolution

<table>
<tr><th>Trend of Evolution</th><th>Justification</th><th colspan="2">Mode of Change</th></tr>
<tr><td>Evolution toward increased complexity, and then simplification</td><td>Re-arrangement and duplication of current parts and parameters will lead to changes of those parameters only.</td><td>PC</td><td rowspan="4">ND</td></tr>
<tr><td>Evolution toward decreased human involvement</td><td>Removal of human interaction from a manual system leads to added functionality in the object being designed.</td><td>NA</td></tr>
<tr><td>Evolution toward the micro-level and increased use of fields</td><td>Technology from other fields is likely required to complete the function using a different technology.</td><td>TP</td></tr>
<tr><td>Evolution toward the micro-level and increased use of fields</td><td>The process of shrinking system size is likely to require the integration of elements and functions into single components.</td><td>FI</td></tr>
</table>

'Trends of Evolution' are used to evolve existing designs, and so will likely only produce a 'New Design' in tandem with another 'Mode of Change'. Thus 'New Design' may result from any trend.

The modes of change resulting from each tool are likely due to the nature of the tools themselves. Both 'Analogies' and 'Trends of Evolution' focus on the current state of the design and how to change it but maintain the same function; whereas 'Assumption Smashing' and the 'Contradiction Matrix' focus on what could be done to the design without placing limits on the existing function. As such, both 'Assumption Smashing' and the 'Contradiction Matrix' change the design space in a far more open-ended way, giving more room for alternative functions to come forward.

'Functional Integration' played little part in this study due to the specific experience of the designer in relation to the task as a whole. Within the designed product there is little to be integrated, however functional elements of the manufacturing process may have been integrated had the designer more knowledge. Similarly, neither 'Modularisation' nor 'Trimming' appeared as 'Modes of Change' in the supported stage due to the small number of parts and functions present in the product.

At the top level of coding it seems that a concept driven by 'New Requirement' is more likely to result in a more creative 'Mode of Change' than one driven by 'Design Improvement'. This stands to reason; a design improvement need not require a significant deviation from the current design, a simple change involving a few parameters may suffice. Conversely, a 'New Requirement' is more likely to significantly add to or remove from the current design, requiring additional creative thinking.

The lowest level of coding suggests a link between the input and output of the process. In most cases, a 'Design Improvement' led to 'Change in Performance', and a 'New Requirement' led to 'Change in Function'. This link is further explored in Section 4.4 below.

4.3 Patterns in Tool Use

When looking at the quality of each concept generated as measured by the company's multi-criteria evaluation table there are cases of each tool being used within the highest scoring ideas, suggesting concept quality is independent of tool use. Regarding the order in which tools were used, 'Analogies' or 'Assumption Smashing' usually started, and the 'Contradiction Matrix' or the 'Trends of Evolution' usually finished. Both of the former are largely flexible tools with less internal structure, and so are easier to implement when an idea is not particularly well formed. Conversely, both of the latter require a fuller understanding of the particular product or contradiction being faced before they can be fully implemented. Therefore they are more effective when an idea has been developed further.

4.4 The Role of Expertise in Tool Selection

During this experiment, the designer was not restricted to certain tools that he could use for each concept; he chose them based on his own expertise and the task in hand. Therefore a question appears regarding the reliability of his expertise, and whether he would have achieved the same results with different tools. The designer had no prior knowledge concerning the overall effectiveness of the tools in stimulating creative ideas when compared to each other. In the case of a 'New Requirement' imposed on the design 'Assumption Smashing' and 'Contradiction Matrix' were consistently chosen, tools shown to extend the design space in a way that accommodates large design changes, incorporating both new functions and changes to geometry or structure. When looking for a 'Design Improvement' the tools consistently focused (for this designer) on methods of changing the design, while maintaining current function completely. There are several implications of these tool choices, with perhaps the most interesting being whether or not the designer's expertise affects the results as a whole. It may be the case that the same design output would have appeared regardless of which tool was chosen, this is hinted at through the link between driving force and final result. Alternatively, this limited study also indicates that the tools may be the factor that decides the form of outcome regardless of the task, as implied by the fact that 'Analogies' resulted only in 'Change in Performance', and 'Assumption Smashing' resulted only in 'Change in Function'. In this case it would be possible to match specific tools to specific tasks or forms of process, optimising design in highly constrained situations. Research would therefore be needed not only to identify and classify tools by the 'Modes of Change' they stimulate, but also to rank them in their effectiveness to individual tasks. The following section describes how this might be done.

4.5 Creating a Design Toolbox

Assuming that the tools do have an important impact on the direction the design process takes, this section looks at how a 'design toolbox' may be formed by classifying tools according to driving factor and the desired output. Table 9 shows the drivers, 'Modes of Change' and outcomes linked to each tool. In each case the coding has only been included if it appeared a majority of times for that tool, i.e. either singularly, or jointly with another.

Table 9: Coding at each level of the design process

Coding Level	**Final Outcome**			
	Analogies	**Assumption Smashing**	**Contradiction Matrix**	**Trends of Evolution**
Driving factor (Top Level)	New Requirement, Design Improvement	New Requirement	New Requirement	Design Improvement
Mode of Change (Middle Level)	New Design	New Auxiliaries	New Auxiliaries	Parameter Change
Outcome of Change (Bottom Level)	Change in Performance	Change in Function	Change in Function, Change in Performance	Change in Performance

As example, 'Assumption Smashing' resulted in a 'New Requirement' at the top level, 'New Auxiliaries' at the middle, and 'Change in Function' at the bottom.

This clearly shows some preference for certain tools towards certain coding at each specific stage. The information in this table can then be re-arranged to link the driving factor of the design to the outcome, showing which tools were used for each process. For example, the driving factor for 'Analogies' was either 'New Requirement' or 'Design Improvement', while the outcome was 'Change in Performance'. Hence 'Analogies' appears in both the 'New Requirement' and 'Design Improvement' rows, but only the 'Change in Performance' column.

Table 10: Ideal tool use based on design driving factor and design outcome

Driving Factor	**Design Outcome**	
	Change in Performance	**Change in Function**
New Requirement	Analogies, Contradiction Matrix	Assumption Smashing, Contradiction Matrix
Design Improvement	Analogies, Trends of Evolution	None

The table therefore suggests that when given a 'New Requirement' for a product, and when looking for 'Change in Function', the best approach would be to use either 'Assumption Smashing' or 'Contradiction Matrix'; and when looking for a 'Design Improvement' with the goal of 'Change in Performance' the best tools to use are 'Analogies' and 'Trends of Evolution'. The implications from this research would be that a designer could look at their brief, and at the outcome that is most beneficial to the product in its own specific circumstances, and could then select tools that would effectively steer the design process in the correct direction. However, to re-iterate what was said before, this logic holds only if individual tools are shown to steer designs in specific directions, and to have a significant impact on the design.

5 CONCLUSION

The application of the previously developed coding scheme to this case study highlights several factors. Of particular interest is the way in which it allows some understanding of the method by which the tools work and their applicability to certain situations. Tools such as 'Assumption Smashing' and the 'Contradiction Matrix' showed a tendency to prompt 'Creative Modes of Change', likely due to the extension of the design space that both initiate. Both 'Trends of Evolution' and 'Analogies', conversely, inspired primarily 'Routine Modes of Change' due largely to the way in which they were used by this designer. The efficacy of the coding scheme and the extent to which the under utilised coding is applicable could be further explored through case studies with more experienced designers and a more functionally complex design task. Additionally, this paper has shown that links exist between the driving factor of a design, the design modification and the design outcome, which may have importance when choosing specific creativity tools for specific tasks.

The study presented in this paper focuses on a highly constrained design task. More studies may be necessary to determine whether the results are supported when observing similarly constrained tasks and to determine the difference from more open-ended design tasks. This would also allow a more detailed analysis of the design coding and the links between the levels, as well as the extent to which the tools affect the final outcome. This single case shows that the coding scheme can be applied to understand how creative tools work, and to study the process by which design ideas evolve.

The coding scheme as applied to this highly constrained design task gives findings in three areas: it provides a method of detailed analysis of the way in which design occurs, including some insight into the nature of creativity seen in such tasks; it enables understanding of the way in which creativity tools work on a fundamental level, and in what ways they will alter the design space; and it shows the importance of the relationships between the driver and final outcome.

ACKNOWLEDGEMENTS

The work reported in this paper has been undertaken with support from the Engineering and Physical Sciences Research Council's (EPSRC) Innovative Manufacturing Research Centre at The University of Bath (grant reference EP/E00184X/1).

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