INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2018, DYSON SCHOOL OF DESIGN ENGINEERING, IMPERIAL COLLEGE, LONDON, UNITED KINGDOM

UNEXPECTED DISCOVERIES AND THEIR ENHANCEMENT OF THE DESIGN PROCESS

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ABSTRACT
The design process has evolved with the inclusion of technology, affecting the creative process. Digital media tools have become for design studios and educational facilities a setting for idea representation, development and communication within the design process. The evolution of digital media tools has shifted from two-dimensional applications to more diverse and flexible three-dimensional scenarios. The inclusion of parameters as modelling attributes give designers new possibilities by which they can enhance their creativity and idea generation processes. The purpose of this study was to identify *unexpected discoveries* as milestones for creativity within two digital media tools; Geometric Modelling Environments (GME) and Parametric Design Environments (PDE). A protocol analysis study was conducted between the two digital environments to comprehend the design process. The level of *creativeness* of each design outcome was contrasted with the digital environment used.

Keywords: Unexpected discoveries, parametric design, creativity, protocol analysis

1 INTRODUCTION

Unexpected discoveries have been defined by Yu, Gu and Lee as those moments occurring within the design process which are not intended by designers while proposing a solution [1]. These discoveries generate a *new* perceptual action, over an *old* action, which could give new meaning and direction to the design process. According to Suwa, Gero and Purcell such discoveries generate dialectic between designers and their ideas through the generation of new requirements or issues that will move the design process further [2].

Through the reformulation of the problem at hand, unexpected discoveries can affect the occurrence of certain actions related to creativity. Darke defined the *Primary Generator,* as a starting point in the *generator – conjecture – analysis* model. Akin [4] defined the *"A-ha" moment*, which sparks creativity within the design process [3]. Chandresekera refers to *Sudden Moment of Inspiration* (SMI), which helps the designer to overcome fixation [5]. Could unexpected discoveries affect the occurrence of these creative moves?

Digital media tools have evolved with the inclusion of mathematical parameters as modelling attributes. Two-dimensional digital media tools which were used to represent ideas are being replaced with three-dimensional digital media tools with different properties. Through the use of mathematical parameters, these new tools can generate models, perform model variations and give diverse representational outcomes. According to Hernandez, this new Parametric Digital Environment (PDE) has replaced singularity with multiplicity [6]. In a comparison between Geometrical Modelling Environments (GME) and Parametric Design Environments (PDE) Yu, Gu and Lee were able to identify the appearance of unexpected discoveries [1].

Since digital media tools facilitate unexpected discoveries, new research must be conducted to understand the incidence of these tools within the design process. This research seeks to understand if the occurrence of unexpected discoveries in GME and PDE affect the creative process resulting in more creative solutions. In doing so, a protocol analysis method is carried out to identify unexpected discoveries and understand how their occurrence affects the final design outcome. Through the comparison between the amount of unexpected discoveries and a *creativeness* scale of the design outcome, a new way to examine how such discoveries contribute to creativity can be measured. With better understanding of how these new tools affect the design process, it will be possible to positively affect new design students' education, through the enhancement and better analysis of unexpected discoveries.

2 LITERATURE REVIEW

Digital media tools have primarily focused on communicating design ideas through two-dimensional (2D) representations, but lately have moved into three-dimensional (3D) representation models of the designed artefact [1]. This development has transformed design tools in Geometrical Modelling Environments (GME) and Parametric Design Environments (PDE). Therefore, it is important to research the design process while using such digital media tools and analyse if *unexpected discoveries* enhance creativity.

2.1 Digital Media and Parametric Design

Maher, Bilda and Gül explored how three different setups could affect design behaviour [7]. The main result of their study was that in a face to face condition, the amount of proposals generated was higher than virtual communication or virtual world. Nevertheless, in the virtual world, the amounts of transformations over one given proposal were higher than the other two conditions. From these results it can be inferred that digital media tools, while liberates cognitive load in the designer and facilitates changes over a given proposal, affecting the amount of proposals generated.

According to Yu, Gu and Lee the usage of software in the design industry has changed [1]. Sketching or drafting software which used a 2D platform has been replaced by more diverse and elaborated 3D geometry modelling software. Such software can be divided in two main categories, Parametric Design Environments (PDE) and Geometric Modelling Environments (GME). The main difference between these two categories resides in the variable parameterisation capability of the PDE. Such parameterisation enhances *unexpected discoveries* which are exploited by the designer. In contrast, *unexpected discoveries* in GME drive the designer to reformulate the design problem [1]. According to Hernandez parametric design can replace *singularity* with *multiplicity* in the design process [6]. This enables the designer to alter parameters in a given design proposal yielding new alternatives for the given problem. Two types of parametric design 3D models are proposed, (1). Existing 3D models which vary through parameter manipulation. (2). New 3D models which result from the combination of previous different parameters [6].

In conclusion, GME and PDE open the possibility of ambiguity and density through *unexpected discoveries* and *multiplicity*. Since almost 20 years ago, Purcell and Gero stated that *computer aided design tools* (CAD) lacked the attributes of ambiguity and density which enhanced the creative process [8]. The question if unexpected discoveries relate to the enhancement of creativity must be addressed. It is important to understand how new design digital environments can affect the creative process. Protocol analysis is a common empirical method used to understand the design process. In this analysis, the designer is asked to "think aloud" while designing [9]. Through protocol coding methods, the researcher is able to understand different actions done by designers in the creative process. This research will focus on decoding the design process comparing two digital environments. The following research questions are addressed.

- Do unexpected discoveries positively affect the design process?
- Would one of the digital design environments stimulate more unexpected discoveries than the other?
- Is there a relationship between unexpected discoveries and the creativeness of design outcome?

The following research method is proposed to study a design process developed in digital media to answer the previous questions.

3 METHOD

The method for acquiring information was divided in two steps. The first step was the utilisation of protocol analysis to capture and code two design processes in digital environments. In this step, two undergraduate design students from senior level were selected. The two students were skilled in the use of digital tools in GME and PDE. Both designers were given a design brief guiding them on designing a furniture solution for the Museum of Modern Arts (MoMA) in New York. The brief had well-defined requirements framing the problem, but still, left enough space for designers to propose new creative design outcomes. This design session lasted a maximum of 120 minutes and was video and audio recorded for analysis and coding. The think aloud method was used for this design protocol. To obtain the protocol, the researcher used two cameras recording the design session. One camera captured the designer's face, looking for facial gestures. Another camera captured the designer's position from behind, looking to see what actions are done on the computer's screen. Figure 1 shows the equipment setup.

Figure 1. Equipment Setup

The second step consisted in measuring the level of creativeness of each design proposal. The final creativeness score was compared to the protocol coding scheme and the amount of unexpected discoveries identified within the protocol to understand if there was a relationship between them.

3.1 Segmentation

The *concurrent verbal protocol* was analysed by dividing it into segments of information. The segmentation procedure used in this research was similar to the Suwa and Tversky scheme, in which each segment was a coherent amount of information relating to one single item/space/topic [10]. Such segment was composed of either one or many sentences, as long as it related to the specific topic being discussed by the designer.

Once segmented, the information was re-grouped according to Chandrasekera's scheme into chunks [5]. See Figure 2. *Dependency chunks* were conformed of subsequent segments which were dependent on one another. Dependency chunks that relate to a distinct phase in the design process were defined as *phase chunks*. *Isolated segments* were those segments which cannot be grouped into dependency chunks or phase chunks [5]. Segments which helped in the moving of design process into new segments were defined as *Focus shift* [5]. Such segments were considered crucial for this research since they may contain unexpected discoveries which drive forward the design process.

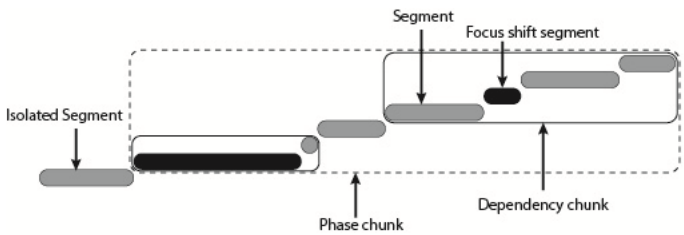

Figure 2. Different Segmentation Elements

3.2 Action Categories

For coding the protocol, each segment was categorised by actions. These actions were grouped into four established categories, *physical, perceptual, functional and conceptual,* according to Suwa, Purcell and Gero [11]. Since the objective of this study was to evaluate the influence of unexpected discoveries in creativity, physical actions involving the digital model were very important. See Table 1.

Table 1. Actions Categorization

Category	*Names*	*Description*	*Examples*
Physical	D- Action L – Action M - Action	Make depictions Look at previous depictions Other physical actions	Representing of any type Observing the representation Hand or facial gestures
Perceptual	P - Action	Attend to features of elements Attend to spatial relations among elements	Geometric formations Proximity, alignment, intersection

		Organise or compare elements	Arrangement of pieces, grouping
Functional	F - Actions	Interaction between people and object	Circulation issues, manipulation
Conceptual	E - Action K - Action	Aesthetic evaluation on preference Retrieve Knowledge	Like – dislike According to previous experiences

3.3 Measuring Creativeness

Measuring the *creativeness* of the design outcome was relevant for this study. The amount of *creativeness* of the design outcome was contrasted with the design process to analyse the relation with the occurrence of unexpected discoveries. Initially we inferred that the larger amount of unexpected discoveries, the larger amount of creativeness. The design outcomes were evaluated through the measuring scheme used by Christiaans based on the Creative Product Semantic Scale (CPSS) [12]. According to him the "CPSS consists of three conceptual criteria: *novelty* - the amount of newness in the design, *resolution* - the amount of functionality and *elaboration and synthesis* - which is the criteria of finished product (pp 46)".

The procedure for measuring the creativeness of each design outcome was carried out by eight judges who evaluated each of the design outcomes according to the established criteria using a Likert scale from 1 to 5.

3.4 Design Task

The design task developed a piece of furniture for the Museum of Modern Art, MoMA, in New York City. The required location of such furniture within the museum was the lobby areas. The main purpose of such furniture was to promote interaction between a minimum of two users. This requirement was suggested as a counter measure against individualistic behaviour in society. The furniture considered an installation area of six feet by six feet, which could be replicated across diverse lobbies of the MoMA. The proposal should enhance the "Latino" culture.

4 ANALYSIS AND DISCUSSION

In order to increase reliability, the two protocols were segmented individually by independent coders. The compared similarity percentages after segmentation between coders were 62% for the PDE protocol and 71% for the GME protocol. Afterwards, a unified segmentation was agreed upon between coders for both protocols.

The total protocol time for the Parametric Design Environment (PDE) lasted 113.5 minutes and covered a total of 81 segments. From this point on this protocol will be referred as *protocol subject PDE*. For the Geometric Modelling Environment (GME) the total protocol time lasted 99.4 minutes for a total of 81 segments. This protocol will be referred from this point on as *protocol subject GME*. Both protocols started with the reading of the design brief and ended when designers generated the first rendered image for their design outcome.

The *protocol subject PDE* is divided in seven phase chunks and nine dependency chunks. The protocol started with a problem framing and idea generation phase which covered 51% of the total time for the protocol without software interaction. The remaining 49% of the total protocol was done in the Parametric Design Environment software. Six focus shift segments were identified representing 6% of the total time for the protocol. The seven phase chunks of the design process can be described to understand the design process. See Table 2.

Table 2. Phase Chunks Protocol subject PDE

Phase chunk No.	*Segments*	*Duration in min.*	*Protocol %*	*Description of phase chunk*
1	1-13	17.3	15%	Problem framing and idea generation
2	15-22	8.2	7%	Idea exploration
3	24-39	16.2	14%	Idea evolution
4	41-45	11.9	10%	Idea synthesis and discussion
5	47-51	7.8	7%	3D Modelling
6	53-72	27.4	24%	Model parameterisation
7	74-81	17.1	15%	Model rendering
	14, 23, 40, 46, 52, 73	7.6	8%	Independent segments

Two unexpected discoveries were identified along the *protocol subject PDE*. The first occurred in segment 45 when through a paper model manipulation; the subject realised that a circular spatial disposition must be discarded since it would not work in the intended interaction. This unexpected discovery became crucial for the designer and changed the geometry of the proposal. Previously, in segment 11 the subject developed a fixation with a circular spatial disposition which was rejected at this point. The second unexpected discovery occurred in segment 71 when through parameter manipulation; the subject changed the furniture's cushion shape. In this case the unexpected discovery was discarded.

The *protocol subject GME* is divided in four phase chunks and ten dependency chunks. In the same way as the *protocol subject PDE,* the *protocol subject GME* started with problem framing and the idea generation. In contrast to the *protocol subject PDE*, the *protocol subject GME* covered 26% of the total protocol time for problem framing and idea generation, while the remaining 74% corresponded to software manipulation. Four focus shifts were identified along the *protocol subject GME* representing only 2% of the total time for the protocol. The four phase chunks of the design process can be described to understand the design process. See Table 3.

Table 3. Phase Chunks Protocol subject GME

Phase chunk No.	*Segments*	*Duration in min.*	*Protocol %*	*Description of phase chunk*
1	1-8	7.8	8%	Problem framing
2	10-27	17.7	17%	Idea exploration and definition
3	29-77	68.7	68%	3D Modelling
4	79-81	3.68	4%	Model rendering
	9, 28, 78	1.54	3%	Independent segments

Three unexpected discoveries were identified along the *protocol subject GME*. The first occurred in segments 37 and 38, when the subject realised that the initially planned seating surface was unviable. Such unexpected discovery forced the change of the seating surface location. This unexpected discovery was the result of software visualisation and manipulation. The second unexpected discovery occurred in segment 56 when the subject realised that there was a *piece* of his initial design that did not accomplished any functional purpose. The subject decided to eliminate that *piece*. The third unexpected discovery occurred in segments 73 and 74 when the colour scheme was assigned to the model. This last unexpected discovery did not yield any formal variation in the design proposal, nonetheless was crucial to determine the colour scheme.

Design outcomes were evaluated with Christiaan's *creativeness* criteria by eight independent judges [12]. All judges were designers with over five years of experience in design education and design practice. The evaluated criteria were: Novelty, Resolution and Elaboration which were scored in a Likert scale from one to five. See Table 4.

Table 4. Creativeness Evaluation

Evaluation Criteria	*Protocol Subject PDE*	*Protocol Subject GME*
Novelty	3.88	2.25
Resolution	3.00	3.63
Elaboration and synthesis	2.88	3.50
Total	**3.25**	**3.13**

The total mean score for the *protocol subject PDE* was 3.25. For the *protocol subject GME* was 3.13. The main scoring difference between protocols was in the *novelty* and *resolution* criteria. For *novelty* criteria, the score for *protocol subject PDE* was 3.88 in contrast with 2.25 obtained from the *protocol subject GME*. This finding is consistent in both cases with the amount of protocol time spent to elaborate the problem framing and idea generation phases. For the *protocol subject PDE* the idea generation phase covered 51% of the total protocol while for the *protocol subject GME* this same phase only covered 26%. Never the less, in the *resolution* criteria, the *protocol subject PDE* obtained a score of 3.00 in contrast with the score of 3.63 obtained by the *protocol subject GME*. In the final criteria of *elaboration and synthesis* the score from the *subject protocol PDE* was of 2.88 while for the *subject protocol GME* scored 3.50. Such results are consistent with the amount of protocol time spent elaborating in each digital environment.

5 CONCLUSIONS

The two compared protocols for GME and PDE initiated the design process with problem framing and idea generation phases. Both of them were addressed through traditional sketching without interaction in any digital environment. Never the less, the design process in *protocol subject GME* presented a more uniform design process with less iteration between phases. Such conditions can be attributed directly to the design skills of the subject, rather than direct interaction with the digital media tool. Even though it cannot be fully supported that PDE generates more novelty in proposals than GME, the question if PDE requires more planning previous to engaging with the digital media tool, hence positively affecting the idea generation phase can be addressed in future studies.

Unexpected discoveries occurred within both protocols which constituted critical points along the design process. Even though not all of the unexpected discoveries were accepted by the subjects, it can be inferred that they affect decision making which moves the design process forward. Hence, unexpected discoveries affect the creative process.

5.1 Limitations

Protocol analysis as empirical research method uses limited quantity of subjects to capture their protocol. Nonetheless, the coded protocol reveals considerable amount of information which represents a design process for analysis.

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