ParaXplore: Demystifying the Exploration of Large Design Spaces

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ABSTRACT

Generative design tools together with large screen displays provide designers an opportunity to explore large numbers of design alternatives. There are numerous design studies on exploring multiple simultaneous designs, but few present interface solutions and system features for such exploration. To the best of my knowledge, no study probes exploring a large design space with multiple simultaneous states. The premise of my research is that, if designers can work directly with large numbers of designs with new representations and tools as part of the design workflow, we should expect new patterns and strategies to emerge and change the design process. Such task environments may present novel actions, task sequences, methods and techniques. What are new actions and techniques that would enable working seamlessly with multiple designs? My research aims to answer this (and similar) questions; and, more specifically, to uncover how designers' augment their work through spatial structuring of the task environment to reduce the cognitive cost of working with multiple simultaneous designs on a large work-surface. I conducted a lab experiment with nine designers. The results suggest design features for new front-end gallery interfaces for managing a large set of design variations while enabling simultaneous editing.

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KEYWORDS

Design space exploration; large design spaces; design process; generative design; use of space

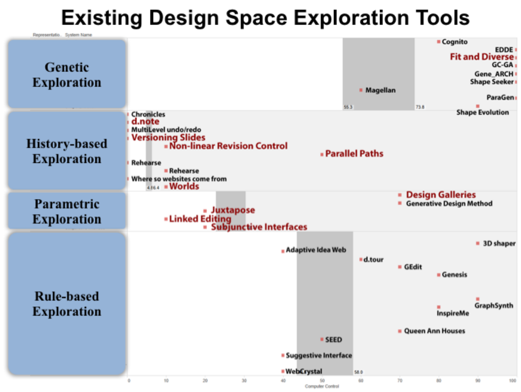

Figure 1: A classification of design space exploration interfaces and techniques

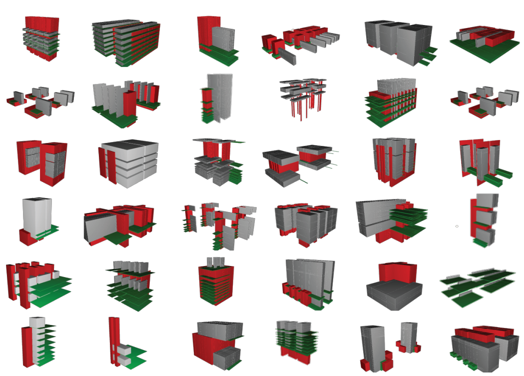

Figure 2: A sample of the dissimilar design variations

1. INTRODUCTION

Generative tools have influenced design practice, by enabling designers to rapidly create thousands of options to explore the previously under-represented, but much discussed design space [10]. Representing this design space, even in partial form, is still a challenge that has been addressed by researchers from different disciplines [1][3][5][9]. Much of this research proposes gallery-like interfaces, which seems like a promising approach. However, these prototypes are usually built on assumptions on how designers might work, rather than understanding what designers actually would do with new and different tools. My research addresses the latter by conducting a lab-experiment observing designers working in a simulated environment supporting a large number of computationally generated solutions. The goal of this experiment is two-fold: 1) to understand the design process of managing a large number of solutions; this includes the action-by-action protocol analysis of the data and the high-level design tasks to achieve design goals; 2) and equally important to understand the designer's workspace management to overcome the cognitive cost associated with working with a large number of design variations simultaneously. Studies in cognitive science suggest that, when experts are confronted with cognition-intensive tasks, they resort to workspace management by intelligently laying out cognitive cues within their task environment [4]. They structure their surrounding space to simplify choice, perception and internal computation [4], however, such behaviors are yet to be observed and confirmed in the design domain, especially when designers work with a large design space. Our study holds value and novelty in exploring the interaction patterns of designers within the over-loaded design space.

Based on these two higher-level research goals, the collected data was analyzed for two inter-related concerns: what the manifested design moves are, and, in response, how the spatial structuring corresponds to observed moves. Correlating this design process with the spatial structuring is important to propose interfaces for exploratory and creativity support tools. These interfaces would then become experimental devices to contribute in describing how designers can work with multiple parallel designs using large displays. The outcome of this research addresses both Computer-Aided Design industry and creativity-support tools. In addition, the results may be useful for interface design in other domains where working with large interactive objects is imperative, such as natural user interfaces, table-top interactions, interactive board games, etc. We expect that the research will initiate a new set of methods to enhance interface design practices.

1.1 Design Process

With the increasing use of generative design methods for design exploration, *sketching-a-solution* is now complemented by *filtering-a-bunch* of plausible solutions out of a large design set. This set can be created using computer-assisted or computer-generated techniques. Our focus for this experiment is to explore how this technological shift has influenced the design process and the embedded design tasks. The results from the study, as expected, show design exploration patterns and a set of exploratory design tasks. In the follow up, we aim to abstract these to a set of system functions for (design) gallery style interfaces to explore a computationally generated design-space.

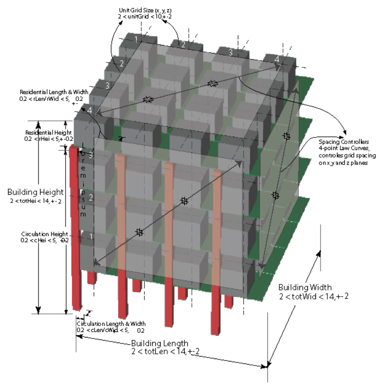

Figure 3: A hypothetical, yet close to real-world design scenario was conceived that was capable of generating a large set of parametric variations. Keeping with Buxton's suggestive ambiguity, it was important for the design scenario to be appropriately abstract, i.e., should have sketch-like characteristics [2]. Parametric variations for this hypothetical building were computationally generated and filtered into 1000 dissimilar designs.

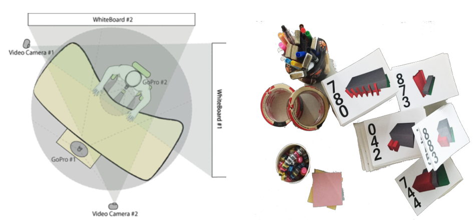

Figure 4: (Left) Experimental Setup; (Right) Experimental Material

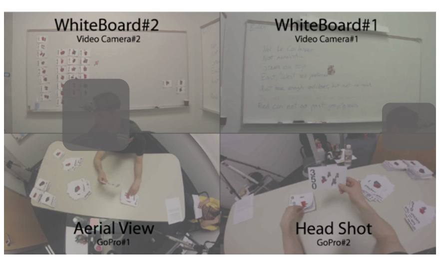

Figure 5: Views from the video recorders

1.2 Spatial Structuring

In our research, we report spatial patterns of design media use and correlate them with the design process observed. We aim to apply the lessons learned to design front-end interfaces, considering the physical surfaces and digital screens (e.g. table-top displays) both have equally limited real estate to work with.

2. BACKGROUND AND RELATED WORK

The main motivation for this research comes from previous academic studies based on observing designers working through goal-oriented design tasks. Design space exploration has been a topic for research since 1980s, however the literature regarding simultaneously working with a large number of alternatives has emerged recently. As part of the background research for my dissertation, I performed an extensive research on design space exploration, its techniques and interfaces. A complete list of those techniques and interfaces (~43) is beyond the scope of this paper. To simplify, I have classified them into four categories based on their underlying representation used for exploration and the degree of automation in performing exploratory tasks. The four categories are Genetic Exploration, History-based Exploration, Parametric Exploration, and Rule-based Exploration. (Figure 1)

Tohidi et al. [7] & Dow et al. [11] both provide enough evidence of a need to work with simultaneous design models. Some researchers report techniques for exploration in computation design media; however few among them allow parallel viewing and editing of models that includes Parallel Paths [6], Subjunctive Interfaces [1], Juxtapose [3], GEM-NI [5] & Design Gallery [9].

All these systems present valuable techniques to develop and edit multiple alternatives, however, there is little evidence of what happens during the process of working with multiple designs. Hence it is hard to settle on one technique. Our research is an attempt towards understanding the process first and then analyze various techniques and interface solutions.

3. RESEARCH DESIGN

For the experiment design, some assumptions were made: a) as a prototype, a tabletop workspace with secondary cognitive artifacts (e.g. pencil and paper) was considered the basic work environment representing an interface; b) designers may move back and forth between design phases—due to time and resource constraints, we limited our experiment to the conceptual design development stage only, as this stage is amenable to exploring many alternatives; c) to capture the natural flow of the design process, the generative model from which design variations were generated was designed to produce functionally sketch-like models that could be interpreted in a variety of ways. Various steps were taken to ensure the computationally generated 1000 variations of the basic model to be visually different from each other (Figure 2). [8]

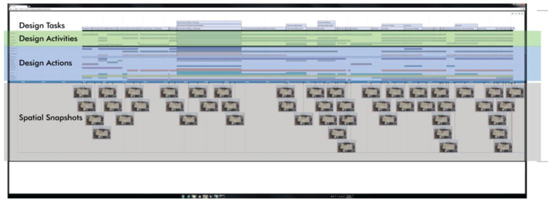

Figure 6: Customized interactive data visualization showing design actions, design tasks and space-use data on a single timeline

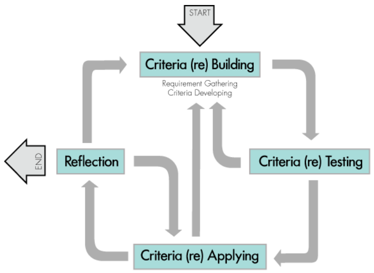

Figure 7: The cycle of Design Tasks

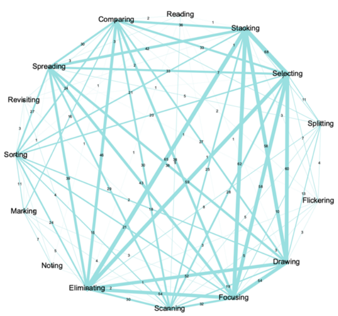

Figure 8: Action Combinations

Table 1: The most frequent actions

Actions	*Frequency*
Stacking	90
Selecting	83
Eliminating	79
Focusing	76
Comparing	70
Drawing	69
Spreading	69

3.1 Experiment Design

As a design task, we asked the participants to consider themselves as the principal architect in a team which had to devise a large set of computer-generated conceptual models for a multi-storey residential building. Participants were unaware of the exact number of variations in the set. They were told that their job was to go through the designs and set goals for the next design phase. In total, purposive-randomized sample of nine (9) designers and one pilot participant performed the experiment under the same experimental condition, using the same material (Figure 4). The participants were pre-screened for general design expertise and their specific experience with parametric modelling. Each experiment session was video recorded using 4 cameras (Figure 5).

4. RESULTS AND ANALYSIS

4.1 Coding

The audio/video data collected, was analyzed and coded at three levels determined after the pilot study and literature review: change-events, design-actions & design-tasks.

A *change-event* is defined as a set of actions, resulted in a visible change on a work-surface. This set of actions can be a single action or a group of repeatedly performed fine actions that resulted in a visible change in the work environment. After the inter-rater reliability (Cronbach's alpha, events = 20; α = .80), one researcher coded the video data and divided the entire design process for all participants, into chunks of observable change-events. A spatial snapshot of each of these events was logged with a time stamp, to record and later analyze spatial patterns.

A *design action* is defined as an observable human action that can easily be observed without any interpretation or association with the design intent. In total there were 15 design actions performed repeated by participants of this study with an inter-rater reliability score calculated using Cronbach's Alpha (actions = 40, α = 0.82). For a complete list of actions see [8].

A *design task* is defined as a group of design actions performed to achieve a certain design goal explicitly stated by the participant. In total five design tasks surfaced based on their repetitive occurrences across the participants: *Criteria Building, Criteria Testing, Criteria Applying*, *Reflection* and *(Re)Setting* (Figure 7).

4.2 Design Process

4.2.1. Design Actions. The results revealed the most frequent actions are; *Stacking, Selecting, Eliminating, Focusing, Comparing, Drawing and Spreading* (Table 1). As expected, participants managed the exploration of the large design space by making collections of alternatives, based on their common attributes. These collections are made through *stacking*, which includes the complete and partial overlay of design alternatives. Participants also used *spreading* action to lay out multiple designs on a surface. They *focused* on designs individually and collectively to identify their features and *compared* designs to justify their selection or elimination patterns.

4.2.2. Action Combinations. While coding, actions were recorded only once within a period of a change-event, even though they might have appeared multiple times. So, to rationalize, every time

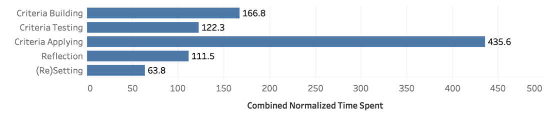

Figure 9: Total time spent of each design task

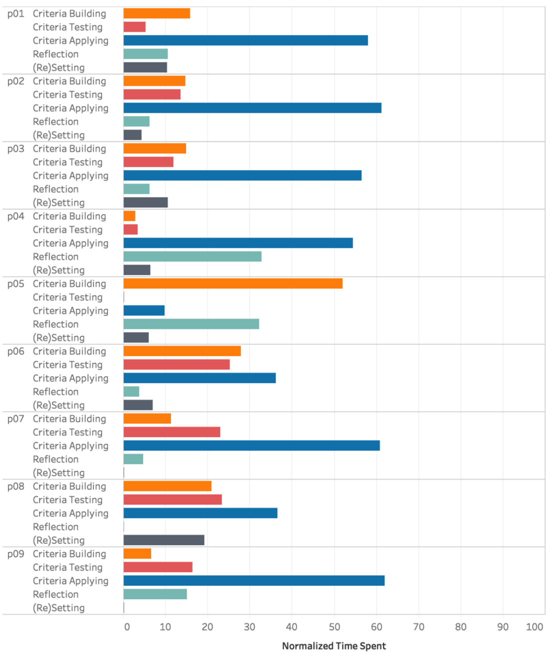

Figure 10: Total Time spent on each design task per participant

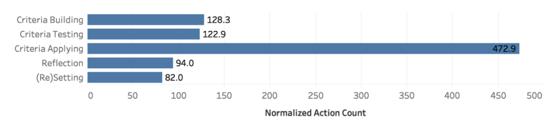

Figure 11: Total number of actions performed during each design task

an action appeared it was counted individually as well as in combination with its co-occurring actions. As expected, the top 10 pairs are the combination of one of the top 5 actions; *Stacking, Selecting, Eliminating, Focusing and Drawing* which is consistent with our action-count data.

4.2.3. Design Tasks. Consistent with the design literature, we observed that the participants followed a cycle of design process (Figure 7), which began by clarifying and defining the initial design criteria based on their preliminary immediate study of a randomly selected set of alternatives. This initial criterion could be based on experience, understanding or designer's insight; it could be subjective or objective, internal or external; but as the understanding of the overall design task developed, the criteria became richer. Once the initial criteria were identified, participants tested them over a few designs before they continued using them over a larger set of solutions in the next cycles. In each cycle, the search became faster and participants very often reflected on their design decisions. They orally confirmed their decisions, spent time looking at a collection, asked questions for clarity, looked for inspiration, and did housekeeping (e.g., clearing up the table for the next filtering cycle).

Criteria Building. During Criteria Building stage, since most of the work involved, understanding the design space and coming up with a strategy to group similar designs, hence the frequent actions included *Scanning. Focusing, Eliminating* and *Spreading.*

Criteria Testing. For Criteria Testing stage, we noticed once the participant has chosen a certain criterion, (s)he will test that criterion first to validate its effectiveness. During this stage, participants are observed to be more careful in their selection process, hence the data reveals the frequent actions include *Eliminating, Selecting, Focusing* and *Stacking.*

Criteria Applying. The frequency of actions performed during the criteria applying stage is the highest. The most frequent actions include *Selecting, Stacking, Focusing, Drawing* and *Eliminating.*

Reflection. During Reflections, participants are observed revisiting the previously seen designs, discussing their design moves and strategizing the next design phase. The most frequent actions during this phase are *Revisiting* and *Comparing.*

(Re)Setting. During this stage, participants are mostly *Sorting, Spreading* and *Stacking* designs.

4.3 Spatial Structuring

This section reports what participants did, analyzed using an interactive visualization (see Figure 6). Our future work involves suggesting how a future system design may accommodate each of these empirical observations.

4.3.1 Zoning. Participants devised various spatial structures by partitioning the work surfaces into zones. More prominently they developed three types of spatial zones: active, analysis and storage zones. Each of these zones initially had tentative locations and loosely defined boundaries, later participants relocated and resized them as needed. The active zone was the immediately accessible workspace with respect to the designer to perform tasks like *comparing, filtering or focusing.* The analysis zone was the *primary* and *opportunistic* workspace where the designers analyzed the selections and develop/refine & revisit criteria. The storage zone was the *secondary*

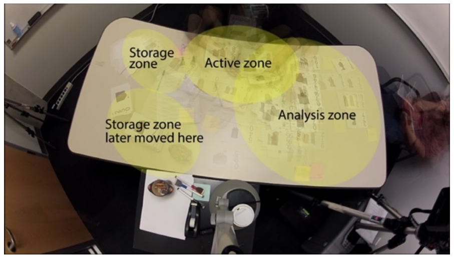

Figure 12: The spatial zones

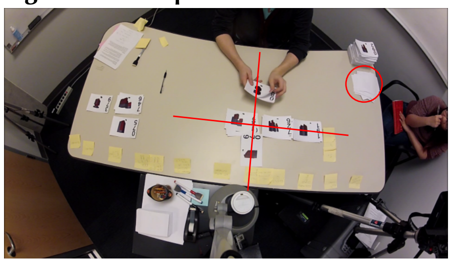

Figure 13: p01 using grid arrangement

Figure 14: (Left) Scanning multiples, (Right) Serial Viewing

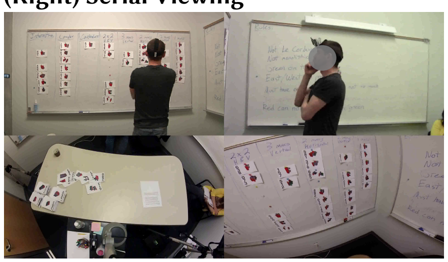

Figure 15: A participant reflecting on his decisions on wall-mounted work surface

space where items were stored and left for later stages. It was the no- or less-attention zone.

4.3.2. Orientation. In this study, participants made local and global arrangements when performing the design tasks. They coded local spaces inside zones, particularly within analysis zone to simplify design decisions. They used aiding devices such as markers and colored stickies to mark alternatives with added information and to code a workspace based on its internal functional property. Participants also plotted physical constraints [4] to block designs from viewing, e.g., some participants placed design cards upside down (Figure 13) to visually mark them as 'seen and rejected', eliminating the need to remember and to minimize the visual clutter on the work surface. We also observed participants placing the cards in portrait orientation to indicate designs with certain property/interest, while placing the others horizontally (Figure 13). This may be used to make an immediately recognizable orientation contrast.

4.3.3. Scanning Mechanisms. Broadly we observed three styles of scanning mechanisms: 1) scanning multiples, 2) serial viewing, 3) Comparing multiples.

5. FUTURE WORK

The results of the experiment provide insights for the design of interactive design alternatives gallery. My next steps involve a) correlating the design analytics data with the qualitative spatial structuring observations; and b) developing a gallery system that will apply the lessons learned from this study to enable designers view and manage design alternatives with least cognitive efforts.

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