A PILOT STUDY OF USING GENERATIVE SYSTEMS IN ARCHITECTURAL DESIGN PROCESS

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Abstract. This paper presents a *pilot study* about impacts that a generative system may have on the architectural design process. The study contains two empirical experiments. The generation experiment studies how experienced and novice designers will utilize such a design system. The formulation/generation experiment observes the problem formulation and solution generation behaviors of less experienced designers. Results of these experiments highlight two issues that require further investigations: 1) domain expertise and modes of interaction that concerns the implementation of future generative systems; and 2) learning through interaction that addresses the use of generative systems in education.

1. Introduction

Generative design systems can assist designers to create feasible design solutions rapidly through generative mechanisms, such as design heuristics, shape grammars, constraint solving, and so on. These systems promise to provide superior design aids to current CAD (computer-aided drafting or computer-aided design) tools, especially during the early design phases. This paper presents a pilot study about impacts that a generative system may have on the architectural design process.

The pilot study focuses on the task of schematic layout design. The generative design system used in this study is SEED-Layout, a schematic layout design tool developed at Carnegie Mellon University (Flemming and Chien, 1995). The aim of this study is to know how a generative system, such as SEED-Layout, will be used by experienced and naive designers, and the effects such a system will have on design behaviors. Specifically, the goal is to study how designers with different levels of knowledge in schematic layout design will utilize such a design aid; and observe if designers' problem solving strategies differ after using the system.

SEED-Layout provides a comprehensive set of functions that assist designers to perform schematic layout design tasks. These functions range from the definition and modification of a layout problem, the generation of layout alternatives, to the evaluation of layout solutions. In SEED-Layout, a layout problem is defined by a group of hierarchically organized functional units, which are constrained by spatial (geometrical) and/or relational requirements. When necessary, SEED-Layout assists designers to modify layout problems to create versions of the original problem, and to manage these problem revisions. For a given layout problem, SEED-Layout allows designers to issue automatic generation of all feasible two-dimensional layouts, to construct layouts manually, or to explore possible layout configurations interactively through step-by-step layout generation. In addition, for each layout, SEED-Layout evaluates it according to all aspects of design constraint setup by designers.

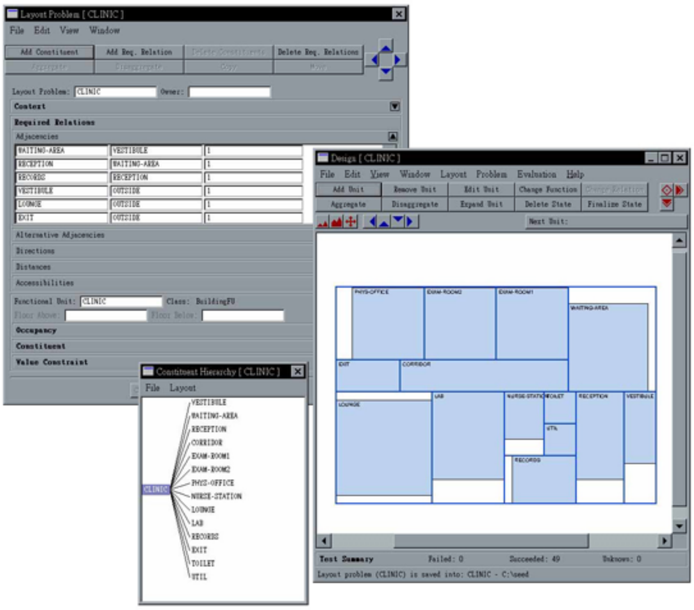

Figure 1. A snapshot of the SEED-Layout environment.

Other empirical studies involving SEED-Layout have indicated that SEED-Layout is fairly complex and its users can be overwhelmed by the variety of controllable functions and the amount of information it can produce in a short time (Chien, 1998). Therefore, the pilot study is conducted in two phases to limit the task complexity and the cognitive burdens on participants. The first phase--the generation experiment--focuses on observing user interactions during the solution generation process. The second phase--the formulation/generation experiment--aims at problem formulation process.

2. The Generation Experiment

The participants of this experiment include experienced designers and novices. Experienced designers are architecture graduate students with at least one-year working experience; novices are first or second year undergraduate architecture students. Participants were asked to perform space planning tasks: solving two layout problems manually in a traditional fashion, and solving a layout problem with the aid of SEED-Layout. For the purpose of comparison, all layout problems are adopted from those used in Akin, et al. (1987) with additional restrictions to the original problems. The entire experiment was audio-taped and later transcribed on paper. For the task that utilizes SEED-Layout, computer keystrokes were collected.

As stated previously, SEED-Layout allows designers to issue automatic generation of all feasible two-dimensional layouts, to construct layouts manually, or to explore possible layout configurations step-by-step interactively. In this experiment, these three types of interaction are named, respectively, AUTOMATIC, MANUAL, and INTERACTIVE. Analyses of data collected for the SEED-Layout-assisted tasks will pay extra attentions to the use of these three types of interaction.

2.1. TASKS

All tasks are of the same type: to design an office layout. For manual design tasks, a list of required spaces, recommended minimum area of each space and requirements on a given site is provided to the subjects. Subjects are required to generate and test solutions against the constraints and requirements stated in the problem statement. For SEED-Layout assisted tasks, a list of required spaces, minimum area of each space and requirements on a given site is modeled in SEED-Layout (see Appendix A). Subjects are required to find a solution using functions provided by SEED-Layout. A 30 minutes time constraint was imposed on all tasks.

To solve a layout problem using SEED-Layout, the problem first needs to be analyzed and transformed into the format that is recognizable by the system. This implies that the user of SEED-Layout has studied the layout problem before he/she can use the system. Since the experiment focused on system functions related to the solution generation, the layout problem was set up for the subjects. However, to ensure that subjects have studied the layout problem prior to using SEED-Layout, they were asked to solve a layout problem manually first then to solve the same problem using SEED-Layout.

2.2. RESULTS

Two subjects, one experienced designer (S1) and one novice (S2), volunteered to participate the experiment. Their tape-recorded verbalizations were fully transcribed for analyses. For the SEED-Layout-assisted task, the analysis involves both paper transcription and system keystroke log to correlate each subject's verbalizations with the particular operation she/he was using. Several differences were found in terms of how experienced and novice designers use SEED-Layout.

2.2.1. Manual vs. Automatic

Results show that S1 (the experienced designer) used the MANUAL layout construction function exclusively. On the other hand, S2 (the novice designer) employed primarily INTERACTIVE and AUTOMATIC functions.

Although S1 did not use INTERACTIVE functions to construction the desired solution, during the interview after the task, the subject demonstrated the idea of exploring space swapping using INTERACTIVE functions. Results also show that S2 thought of using the AUTOMATIC operation, however were hesitated to apply it from the very beginning because the search space would be huge. Instead, S2 chose to allocate the three larger spaces first using INTERACTIVE operations; evaluated those partial solutions (with 3 spaces allocated); then applied AUTOMATIC operation to those partial solutions that thought prominent.

2.2.2. Commanding vs. Consulting

S1 showed commanding tone when interacting with SEED-Layout, whereas S2 was in a consulting position. Below is a segment of S2's protocols:

21 see what else they think...
22 ... I want the secretary and chief engineer...
23 um... I don't want the conference like this...
24 oh... I might as well try to see what they do with what I had originally setup...
25 are they all sort of by a door?
26 just target the next 2...
27 now I'm just trying to see what they think there would be... different setups for the engineers

2.2.3. Learning

Additional observation showed that after performing the SEED-Layout-assisted task (task 2), S1 indicated a new strategy "swapping spaces," which had not been mentioned in performing the first task (task 1). This new strategy was referred several times when the subject was performing the last task (task 3). This phenomenon did not appear in S2's problem solving behavior.

3. The Formulation/Generation Experiment[i]

The experience gained in the previous experiment led to the creation of a "SEED-Layout Tutorial" (Chien, 1999) to help designers get started with SEED-Layout. This self-guided tutorial enables the second phase of this pilot study to observe the design behavior during the problem formulation and solution generation process.

The participants of this experiment include third and fourth year undergraduate architecture students. Participants were asked to perform space planning tasks: solving one layout problems manually in a traditional fashion, and solving another layout problem with the aid of SEED-Layout. Same layout problems from the phase one experiment were used in this experiment. The entire experiment was videotaped and later transcribed on paper.

3.1. TASKS

Tasks are similar to those used in the previous experiment. The manual design tasks are the same as the previous ones (but in Chinese instead of English) with a 30-minute time constraint. However, for SEED-Layout assisted tasks, subjects are required to analyze and formulate the layout problem first, then find a solution using functions provided by SEED-Layout (See Appendix B). A 40 minutes time constraint was imposed on this type of tasks.

The manual design tasks were conducted by subjects in a two-person group without supervisions. The SEED-Layout-assisted tasks were conducted individually with an experimenter.

3.2. RESULTS

Thirteen subjects participated the experiment as a required assignment for an elective course. At the time of this writing, only two tape-recorded verbalizations were transcribed for analyses. Both subjects (T3 and T4) are third year architecture students. Several similarities were observed in terms of their design behaviors during the SEED-Layout-assisted task.

3.2.1. Mixed Use of Manual and Interactive Operations

Both T3 and T4 used MANUAL operations frequently to achieve desired layout configurations. However, when MANUAL operations failed to produce valid layouts (i.e. layouts with constraint violations), both subjects employed INTERACTIVE operations to generate alternative layouts. The AUTOMATIC operations were rarely used: T3 and T4 each used only once.

3.2.2. Relying on Manual Evaluation

The manual evaluation here refers to a subject's personal evaluation on a particular layout configuration, as opposed to the automatic evaluation performed by SEED-Layout. Both subjects' protocols showed long pauses of interaction while they were evaluating the particular layout displaying on the screen. T3 and T4 performed some evaluations that are already completed by SEED-Layout; for instance, checking adjacency relationship. Other evaluations, primarily circulation patterns and daylight considerations (these are not supported by SEED-Layout), were also performed by both subjects.

The protocols also indicated that both T3 and T4 relying heavily on the manual evaluation to determine the final solution. During the last part of the test, both subjects were observed frequently switching between several candidate layouts before making their final decision.

3.2.3. Lack of Associations between Problem and Solutions

Neither T3 nor T4 realized the causal relation between a problem formulation and the generated layout solutions until it was explained by the experimenter. For example, T4 formulated the layout problem with eight relational constraints and minimal width and area requirements for each space. When an INTERACTIVE operation failed to produce a layout due to a violation of an adjacency constraint, T4 showed confused and did not recall she/he had set the constraint in the problem.

The protocols showed this behavior happened frequently when the subjects were changing their focuses of design considerations. Akin (1988) describes this change as an act of problem restructuring. This, in turn, may cause changes to the original problem formulation in a subject's own mind but not the problem in the computable form, and thus create inconsistencies between these two forms of problem representation.

4. Discussion and Future Work

At present time, this pilot study cannot draw conclusions from the limited amount of data examined. Nevertheless, results from the two experiments highlight two issues that will be addressed in the future work of this research.

4.1. EXPERTISE AND MODES OF GENERATIVE INTERACTION

From the results, one may hypothesize that experienced designers tend to use MANUAL or INTERACTIVE method to solve the problem whereas novices may use INTERACTIVE or AUTOMATIC method more often. On a closer look at the domain specific expertise of each subject in this study, this hypothesis becomes more convincing. S1 was a Ph.D. candidate who holds a bachelor and a master degree in architecture and had eight years of working experience. S2, on the other hand, was a second year architecture student with no professional experience. T3 and T4 were third year architecture students with prior architecture training in vocational schools (for three years) and part-time working experience. In addition, T3 had another three years of full-time working experience. Figure 2 shows this hypothesis in a pictorial form.

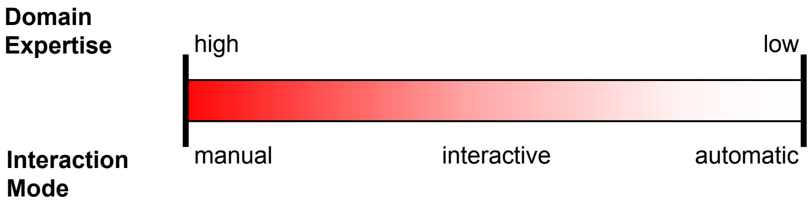

Figure 2. Expertise and Modes of Generative Interaction Hypothesis

Drawing from the common sense, one may find it easy to confirm the hypothesis: experienced designers had acquired the ability to solve layout problems thus need less automatic assistance, which may be needed by less experienced designers. However, formal investigations into this issue are necessary to provide design aids that are effective and efficient for their intended users. If this hypothesis holds, systems for professional use need not provide fully automated solution generation but may require sophisticated evaluation functions. Contrarily, systems for novice designers may need to provide information navigation aids to help designers managing solutions automatically generated by these systems (Chien and Flemming, 1997; Chien, 1998).

4.2. LEARNING THROUGH INTERACTION

The results show that a certain amount of domain learning occurred through interacting with SEED-Layout; for instance, S1 realized a "space swapping" strategy. However, for the less experienced designers in this study, the learning effect cannot be observed. What's there in SEED-Layout that can be learned or deduced through interaction? How to make SEED-Layout a teaching aid to help novice designers improve domain knowledge through interaction? These two questions will be address in the future work.

Acknowledgments

The first phase of this pilot study was conducted in Carnegie Mellon University. Discussions with Professor Herbert Simon provided help in developing the test set-up and analysis of the experiment. Gratitude also goes to the SEED team, especially Professor Ulrich Flemming, for the use of the SEED-Layout program.

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Appendix A: Sample Task Sheet for the SEED-Layout-Assisted Task in the Generation Experiment

Task 2

Please solve the layout roblem which you just did in task 1 using the com uter system provided here. The site and s aces information is already setu for you (see the table below). Please use the functions provided by the system to find a solution (or plausible solutions). You have 30 minutes to solve the roblem. Please try to think aloud during the process.

Please note that due to the limitation of the system, door and window locations are not modeled in the system. If you have any roblem using the system, please don't hesitate to ask for assistant.

Constraints:

(units: **cm** and **cm^2**)

space	min. wid h	min. area	o hers
Chief Engineer	290	87000	direct access to outside in N/S direction
Secretary (including reception area)	240	90000	direct access to outside in N/S direction
Staff Engineer1	195	45825	
Staff Engineer2	195	45825	
Conference	320	108800	

Appendix B: Sample Task Sheet for the SEED-Layout-Assisted Task in the Formulation/Generation Experiment

辦公室空間配置

請利用 SEED-Layout 將下列空間配置於下圖所示之基地中。
※由於 SEED-Layout 無法處理開口部（門或窗），請自行評量最後的平面配置是否配合基地中開口部的位置考量。
設計時間為四十分鐘。
過程中，請以「邊作邊說」的方式，把心中的思考立刻用語言表達出來。

空間使用需求與最小尺寸建議值 (單位：公分)

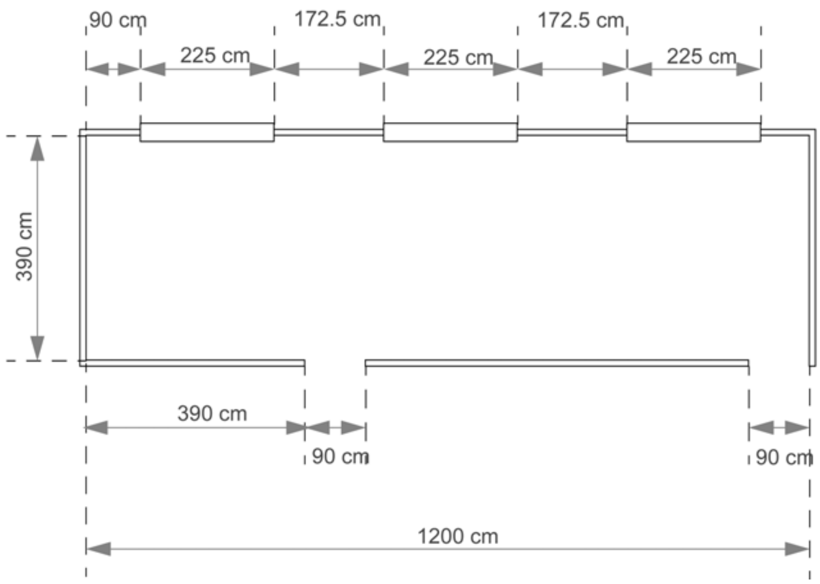
主任工程師	290x300
秘書	240x300
二名工程師	每人 235x195
會議空間	340x320
接待空間	120x150

※提示：定義各個空間，每個空間的尺寸設定

其他要求

主任工程師希望有隱密性。
秘書應靠近接待空間。
※提示：限制條件的設定

基地



[i] All materials used and collected in this experiment are in Chinese.