CAPTURING INTERPRETATION SOURCES IN ARCHITECTURAL DESIGN BY OBSERVING SEQUENCES OF DESIGN ACTS

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Abstract. Prototyping is important for design exploration. While various computer-aided conceptual design systems (CACD) aim to support this practice, they are somewhat limited in their ability to suggest interpretations in-context. To improve these systems, we need a better understanding of how designers interpret things when designing, and what factors influence this activity. We observe architectural designers' design process, and conducted a deep analysis of the activity at several levels, to capture interpretative events. The analysis of these reveals interesting patterns of design interpretation, which may be used to enhance future CACD systems.

Keywords. Design process; Design computing; Reinterpretation.

1. Introduction

Compared with CAD systems, prototyping in the early design stages (via sketching, using physical models etc.) consists of a dynamic communication between the design representation and the designer (Schon and Wiggins 1992). This communication, which can be seen as a 'seeing-moving-seeing' process, allows the designer many opportunities to reinterpret ambiguous forms and generate new ideas.

CACD systems, which target the early design stages, aim to support this practice. Specifically, systems focusing on interpretation can help designers in changing their perspective of the design, when designing (see for example, "The Creative Sketching Apprentice" by Karimi et al., 2019). However, current systems are limited in their ability to suggest interpretations based on the design situation.

Since design can be seen as a sequence of situated acts (Gero 1998), interpretations should not be discussed in isolation. In short, the situation affects our knowledge and view of the world (Kelly 2011), and thus our interpretations. Therefore, to enable computational systems to realistically support interpretation in conceptual design, it is important to understand interpretation in context. One important aspect is the following - how do past events affect the representation and interpretation of future designs?

This paper sheds some light on how designers get inspiration from past events, to interpret design representations based on the design situation. Designers

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generate interpretations by constructing representation of the artifact, and attributing a meaning to the artifact (Tversky et al., 2003). This can provide a new way of understanding and observing the design process.

The structure of this paper is as follows: we first introduce the relevant background regarding interpretation in design. Then, we describe our design task and its analysis. Next, we introduce results extracted from our analysis regarding interpretation. Finally, we discuss their implications with respect to CACD systems.

2. Background

2.1. INTERPRETATION IN DESIGN

Interpretation plays a central role in design (Goldschmidt 1988), for two main reasons: first, it is the bridge between reality and imagination (*figure 1*), shaping 'the way that the external world comes to be represented internally by a designer' (Kelly 2011, p21). Since design can be regarded as 'seeing-moving-seeing' process (Schon and Wiggins 1992), the two-way communication between designers and design representations depends on interpretation. Second, interpretation aids in design exploration, since design representations are ambiguous (Jowers and Earl 2014) - for example, a designer can give the same sketch many different meanings in different situations.

Figure 1. Interpretation is the way that the external world comes to be represented internally by a designer (based on Kelly 2011).

The process of generating interpretations can be divided into two parts: first designers reconstruct their mental representation of the artifact (perceptual reorganization), and then they attribute a meaning to a part of the artifact itself (Tversky et al., 2003).

We redefine these two steps with the help of the situated FBS ontology proposed by Gero and Kannengiesser (2004). Perceptual reorganization takes place on "structure" (the artifact's components) and the meaning assigned is often related to their "function" (purpose). Since in our study we focused more on low-level of observations to discover general phenomena of interpretation, so we did not include the notion of "behavior", which is a part of the above model.

2.2. ANALYZING DESIGN PROCESSES

Design can be seen as a sequence of situated acts (Gero 1998), so it is necessary to observe interpretation within design situation. Before analyzing specific interpretations, it is useful to visualize the entire design process, to see the big picture.

Linkography is a method for visualizing design processes, developed by Goldschmidt (2014). It shows the process as a series of events referred to as "design moves". A "linkograph" are is a graph constructed from design moves ('an

act which transforms the design situation', Kan and Gero 2017, p24) and "links" ('the connection between moves using domain knowledge and common sense', Kan and Gero 2017, p25). Linkographs can serve two purposes in our work - helps in searching critical moves in the entire process, and find other moves which are related to these.

To form Linkographs, researchers use protocol analysis - a method that records the externalization of thoughts in real time. In this analysis, researchers transfer the data into transcript, then categorize the transcript using specific rules. Categorization enables a common language for identifying important patterns. Some protocol studies focus on design collaboration process. For example, Christensen and Ball (2016) have examined the effects of background knowledge on the ability to analogize in teams. In another world, Song et al. (2003) have found that teams with high semantic variation explored design solutions broadly. These have broadened our horizons when constructing our analysis method.

We list some shortcomings in existing analysis methods for observing interpretations in design processes. First, designers do not just communicate verbally, they also use design representations like sketches to express their ideas. Hence verbal and visual data cannot be discussed separately. Linkographs do not propose a clear way to integrate these. Second, because interpretation links the external and internal worlds (Kelly 2011), we need to distinguish between these, when analyzing interpretation. However, Linkography does not make this distinction, and therefore cannot account for the interaction between different worlds.

3. Method

3.1. APPROACH

To observe interpretation during a design process, we devised a design task, in the context of architectural design. We began by conducting an initial experiment, in which two designers were asked to co- design a building complex of a design office and residence (face-to-face). They were asked to come up with a complete set of floor plan sketches. We video recorded their conversations, and documented their sketches and notes.

In the initial experiment, we observed how designers assigned meaning to design representations, based on previous events in the course of design. We relied on Gero's original definition of "structure" (Gero and Kannengiesser 2004), and further defined it as visual representation including a shape or a group of shapes. Further, based on Gero's definition, we further identified a narrow definition of "function" - the purpose of architectural elements as a component of a structure in architectural design. A function could be specified using either an architectural element (for example, a door) that contained many sub-functions, or introduced verbally using phrases like 'through it we can see outside' (a general function).

By comparing the work done by the designers at the initial experiments, we found that the initial experiments lacked constraints, making the design process difficult to compare between different groups. Based on these initial findings, we have improved the experiment, as explained below.

3.2. DATA COLLECTION

First, we decided regarding the skill-level of the participants. We chose architectural design students who had at least a bachelor's degree in architecture, and in the age range of 22-30 years old, because they would have a shared expertise and an ability to use language and shape to express their ideas. To let the participants express their thoughts naturally, they were asked to work in pairs. The maximal duration for the task was 45 minutes. We conducted five sessions with the help of 10 participants (in 5 groups).

Second, due to the effects of COVID-19 the experiment could not be conducted face to face. However, we wanted to ensure that the participants from each team could communicate and design in real time. As a solution to this, we resolved to use Google Meet to have a voice call and Figma (a co-design platform) to share design in real time. The participants connected via their personal computer with a microphone in a stable internet environment. The entire design process, including the conversation was video recorded.

It is worth noting that such platforms, designers can only share their ideas through shapes and conversations. This is in contrast to face-to-face designing, where we can quickly show notes, sketches of relevant cases, and express ourselves in body-language, to convey our ideas - all of which facilitate smooth communication. On the other hand, using Figma allowed designers to focus more on the expression of ideas in form, which is important for this work.

Third, we revised the design task. The new task (*figure 2*) focused on designing a facade of an architectural office for three architects. Several design requirements, the surrounding buildings and the boundary of the site, were given as initial information. We chose the facade as the focus of our design task because it reduced the amount of work involved in drawing floor plans, but allowed the designers to design while imagining the entire building, its function and its relationship to its surroundings.

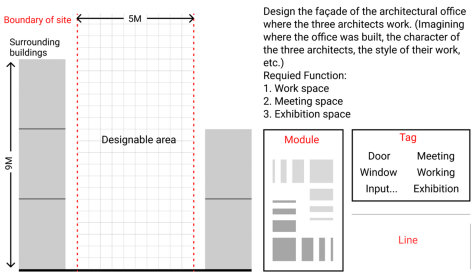

Figure 2. Interface of design experiments in Figma (English version).

To make the design more realistic and facilitate creativity, we started by asking the designers to imagine a specific site, the work styles of the three architects, etc. In order to control the complexity of the design and to ensure comparability, the designers had to complete the design by using a predefined set of modules. We provided the designers with four sizes of modules and presented them in two

gray-scales and two orientations. The original modules did not have any meaning, and the designers could assign meaning to the modules freely during the session (however were not instructed on how to do so). The site was divided using a 10 x 21 grid, which constrained the location for placing modules. Finally, to observe and record architectural elements more clearly, we provided designers with editable tags and lines, for easy annotation.

3.3. DATA ANALYSIS

3.3.1. Analysis of design process

Each design session was timed at 45 minutes. We first converted the recorded conversation into a transcript. Phrases like 'Yeah', 'emm', 'I see', etc. which didn't have a clear meaning in the conversation were omitted. The transcript was segmented into design moves based on the number of acts and points raised by the designer in the recording, and links were created between the design moves based on the current topic mentioned in the conversation, and the current action performed in the video. Additionally, when seen as useful for getting further insight, we also drew a Linkograph.

3.3.2. Selection of episodes

We revisited five design sessions, and extracted critical episodes which were rich in interactions between designers and design representations. For considerations of understandability, we selected two examples from different degrees of complexity, which reveal some common findings.

3.3.3. Relating Structure and Function

To create a rich representation of the interactions in the episode, we divided the world into 'internal' and 'external' worlds (Gero and Kannengiesser 2004). Notice that we treated the two designers in each group as having a shared interpretation space. For clarification, we only use interpretation in a symbolic way. Therefore, when one designer proposes some interpretation and make his/her collaborator aware of it, we regard them as having a shared interpretation (which appears in the internal world). To present the interaction of design ideas over time, we added an additional category of 'previous'. We placed the events and relations in these three dimensions (*figure 3*).

We extracted the design moves in which meanings were assigned, and combined these with the current structure, as a basis for forming our diagrams.

In the external world there are 'structures' that represent design representations ['S(x)'], in the internal world there are 'architectural elements' that represent collections of functions ('E(x)') and 'functions' that represent a specific function ['F(x)']. Additionally, in the category of 'previous' there are 'previous events' that represent design requirements, past design moves and past experiences etc. ['(P(x)']. In all cases, x is a serial number assigned to these. We used lines to represent the relationships between these entities, and arrows to indicate the possible direction of causation. Each line was labeled with a number,

indicating the order in which it occurred (identical numbers indicate simultaneous occurrence). When two related entities are in the same world, they were connected by solid lines; if not, they were connected by dashed lines. Finally, we took a screenshot of the designer's design process, and framed the part of the drawing that corresponds to the current structure.

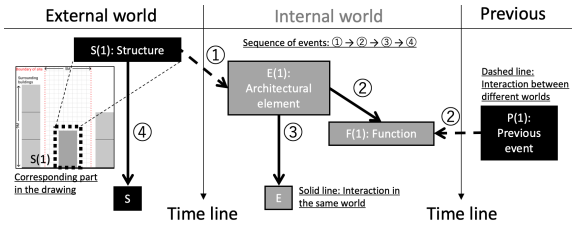

Figure 3. The way to read the diagrams with structure and function.

4. Result and discussion

4.1. EPISODE 1 - 'DESIGN FACTORY'

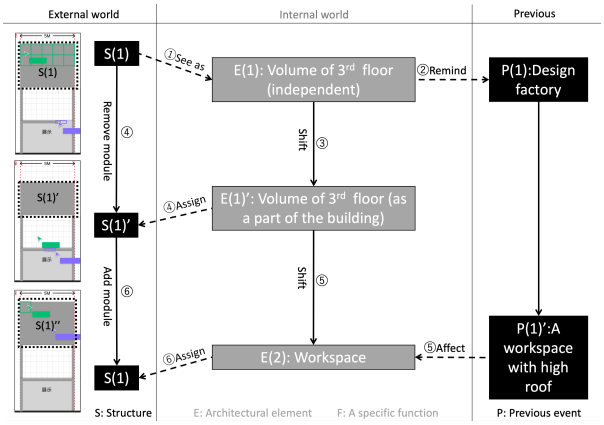

Figure 4. Sequence of events in episode 1.

The designer created S(1) by accident, when copying and pasting modules. Sequence of events: 1-The designer interpreted S(1) as the volume of the third floor E(1) and discussed the size of the volume independently; 2-The large volume of the third floor E(1) reminded the designer of a familiar place called 'design factory' P(1); 3-When the designer considered the third floor volume as part of the building E(1)', he found it was too large; 4-He reduced one layer of modules to create S(1)', and assigned E(1)' to S(1)'; 5-The designer said that the 'design factory' was a workspace with a high roof P(1)', and he thought it would be good to design the third floor to be a workspace E(2), with a high roof; 6-The designer added the removed modules back to create S(1) again and said that the third floor

could be used as a workspace like the design factory, which has a high roof (*figure 4*).

Pattern 1-1 (*figure 5*): *structures and functions interact to produce new interpretations and structures*. The designer initially interpreted S(1) as the volume of the third floor E(1). However, when the designer saw the volume as part of the whole building E(1)‘, he felt that the volume was too large. So he removed some of the modules and transformed S(1) into S(1)’.

Pattern 1-2 (*figure 5*): *functions and past events interact to produce new interpretations*. The designer initially interpreted S(1) as the volume of the third floor E(1). The large size of S(1) reminded the designer of a place called ‘design factory’ P(1). The designer remembered the ‘design factory’ as a workspace with a high roof P(1)‘. This memory P(1)’ led the designer to reinterpret the volume of the third floor E(1)‘ as a workspace E(2), then the designer thought the original large volume S(1) was ideal and enlarged the S(1)’ back into S(1).

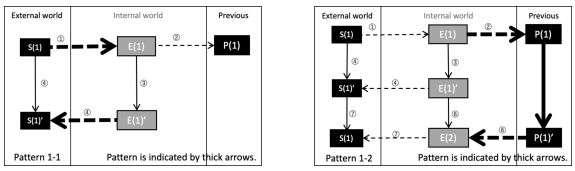

Figure 5. Patterns in episode 1.

4.2. EPISODE 2 - ‘ROOF FIELD’

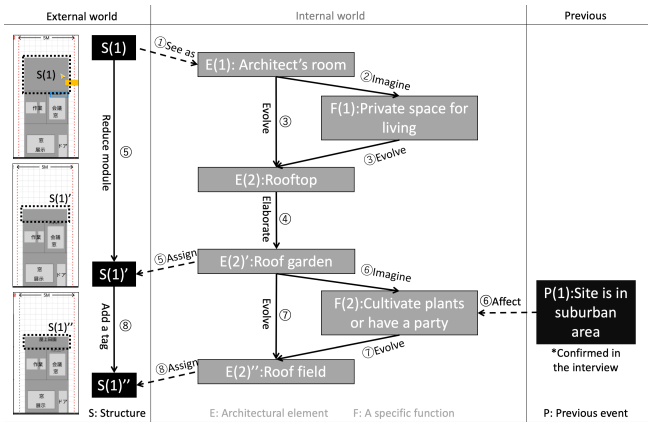

Figure 6. Sequence of events in episode 2.

Sequence of events (*figure 6*): 1-The designer discussed the use of S(1), suggesting that it could be used as the architect’s personal room E(1); 2-The designer began to imagine the specific functions for the architect’s personal room, thinking it could be a space for living F(1); 3-The designer suddenly felt that F(1) is not necessary,

thereby suggestin that the third floor could be turned into a rooftop E(2); 4-The designer said the roof can be used as roof garden E(2)'; 5-The designer felt that the current S(1) was too large for a roof garden E(2)', so he removed some of the modules to create S(1)'; 6-While imagining the specific functions of a roof garden E(2)', the designer was inspired by the idea of a site in the suburbs P(1), and felt that cultivating plants and having a party F(2) on the roof would be more suitable for an idyllic landscape; 7-The designer felt that a 'roof field' E(2)" was more suitable for this building than the rooftop garden E(2)'; 8. The designer added a tag 'roof field' to create S(1)".

Pattern 2-1 (*figure 7*): *the combination of architectural elements and their specific functions lead to an innovative interpretation*. Based on the architect's personal room E(1), the designer imagined the specific function F(1) of the room, which led the designer to realize that a personal room E(1) was not necessary for the building, thus proposing a rooftop E(2) instead of personal room E(1).

Pattern 2-2 (*figure 7*): *past events may influence the formation of interpretations and help the designer to imagine a specific function*. The designer set the site in the suburb P(1), at the beginning. When he imagined the specific function of the roof garden E(2)', he felt that cultivating plants F(2) was more in line with the idyllic landscape of the suburb. And, *the combination of the architectural elements and their specific functions has lead to an innovative interpretation*. Under the combined influence of the roof garden E(2)' and cultivating plants F(2), the designer transformed the roof garden E(2)' into the 'roof field' E(2)''.

Pattern 2-3 (*figure 7*): *a new interpretation is based on past interpretation*. The designer initially designed a rooftop E(2), then elaborated it into the roof garden E(2)' which finally evolved into the 'roof field' E(2)". These three architectural elements are all about the roof and quite similar. This shows a possible tendency to keep previous interpretations and apply them to the new situation.

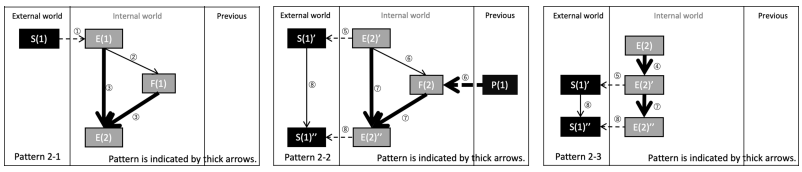

Figure 7. Patterns in episode 2.

4.3. DISCUSSION

Several findings arise from this study. First, we observed two fundamental interactions: one between structure and function (Pattern 1-1), and the other between function and past events (1-2), which are difficult to observe in Linkographs. This implies that our method can enhance inquiries into interpretation. Second, we found that the current structures and functions (2-1), and past events (2-2) are all possible sources of interpretation, and can individually or collectively influence the formation of interpretations. Third, based on the

patterns we have found, we identified two main categories: patterns that apply original architectural elements to new situations (2-3), and patterns that combine architectural elements and their specific function to create new interpretations (2-1 and 2-2).

Finally, we have identified interesting relations with existing models for implementing human-like memory in computational design agents, such as the "constructive memory" (Gero and Fujii 2000), and specifically with the notions of "push" and "pull" from memory, proposed by Kelly and Gero (2015) as basic components for design agents. 'Push' refers to the act of remembering something via being affected by the environment (for example, I hear my pet cat calling which reminds me that I need to feed it) and 'pull' refers to intentionally remembering something (I try to recall the name of an old friend).

In our experiment, we observed the occurrence of both 'push' and 'pull' in interpretation. In episode 1, S(1) was created accidentally by the designer while copying and pasting the modules. This unexpected structure was interpreted by the designer as the volume of the third floor, 'pushing' the designer to remember a place called the 'Design Factory'. The way that the designer stopped designing and thought about the 'Design Factory' more deeply seems related with the idea of 'reflection-in-action' (Schön 2011), which is important for designing professionally. The moment of reflection allowed the designer to transform the 'Design Factory' into a workspace with a high roof, and had driven the designer to change the modified structure back to its original S(1), and interpret it as a workspace with a high roof.

In second-order cybernetics (Herr and Fischer, 2019), Stafford Beer (1972) proposed a five-layer model for organizational structure that balances survival demands in an environment, named the viable system model. We have identified interesting relations between our design episode and this model, specifically with respect to layers 4 and 5.

In episode 2, the designer suddenly felt that the space for living F(1) was not necessary, so that the original idea of an architect's personal room E(1) had lost its importance. However, the visual representation S(1), related to E(1), still existed in the external world, letting the designer create rooftop E(2) to replace E(1). This process corresponds with layer 4 (a system responding to the external world). In another example, the designer began by setting the site in the suburb P(1), and the idyllic landscape became one of the design themes. This drove the designer to expect to cultivate plants on the rooftop F(2), transforming the current roof garden E(2)' into the roof field E(2)". This process corresponds with layer 5 (a system dealing with internal policy decisions), considering that a theme can be seen as a loose policy in architectural design.

5. Conclusion & Future work

Nowadays, more and more efforts are made to build CACD systems that can flexibly and actively support designers, like the system by (Karimi et al., 2019). Such work is naturally expected to draw on research in design cognition (Ashok et al. 2012), towards understanding and modeling human design capabilities.

This study has proposed a method to systematically observe interpretations, by relating structures and functions, and demonstrated its use for extracting patterns of interpretation in designing. These can be used to deepen our understanding of interpretation in design. Furthermore, they provide a basis for discovering specific rules for implementing interpretative processes in CACD which engage in interpretation.

We now know of certain factors shaping interpretation, however the actual their interaction should be studied in depth. It is as if we have identified several of the unknowns in the equation, but have not clarified their coefficients. For future work, we aim to refine and generalize such patterns of interpretations, as we observe the process in greater detail. For example, we wanted to trace what kind of things reminded the designer of past events. Additionally, we intend to focus on key patterns, and search for more specific rules associated with them.

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