How an Architect Created Design Requirements

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Abstract. There is an anecdotal view that designers, during a conceptual design process, not just synthesise solutions that satisfy initially given requirements, but also create by themselves novel design requirements that capture important aspects of the given problem. Further, it is believed that design sketches serve as a thinking tool for designers to do this. Then, what kinds of cognitive interaction with their own sketches enable designers to create novel requirements? The purpose of this paper is to answer this question. We examined the cognitive processes of a practising architect, using a protocol analysis technique. Our examinations focused on whether particular types of cognitive actions account for the creation of novel design requirements. We found that intensive occurrences of a certain type of perceptual actions, acts of establishing new relations or visual features on the sketches, are likely to co-occur with the creation of requirements. This suggests that this type of perceptual actions are the key constituent of acts of creating novel requirements, and therefore one of the important actions in sketching activities. This presents evidence of the view that designing is a situated act, as well as has an implication for design education.

Keywords. design requirements, sketches, design cognition, protocol analysis

1. Introduction

How do designers work on a conceptual design? Does it suffice for a designer to synthesise solutions that satisfy initial design requirements given to them at the outset of the design problem? The answer is no for the following reasons. First, some of initial requirements could be too abstract to serve as practical constraints to the design process; designers have to understand the gist of the abstract requirements and thereby generate more concrete ones that constrain the design problem in a practical way. Second, initial requirements do not necessarily capture important aspects of the given problem; designers themselves have to create important design requirements during the process.

Thus, the creation of novel design requirements that are specific and important is one of the central acts for a designer. We will give an example of this act from the experiment we carried out using a practising architect. The architect, as he worked on the conceptual design of a museum on a given site, created an important design requirement in the middle of his design process; the arrangement of outdoor functions, such as a pond, a green area or a sculptural garden, should be able to attract the attention of people who pass by along the public road, so that people may feel like visiting the museum in future. This particular requirement became one of the primary requirements thereafter in his design process; finally, he decided to arrange monumental sculptural pieces on the edge of the site so that they are visible from the public road. Getzels and Csikszentimihalyi (1976) presented evidence from a longitudinal study of art students which suggests that the act of creating requirements, i.e. what they refer to as problem-finding behavior, is strongly associated with creative outcomes.

How do designers create novel design requirements? Do designers commence with an analysis of the given problem to list up important requirements, then synthesise solutions that satisfy those requirements, and finally evaluate the solutions? The answer is no. Designers do not go through these phases in a sequential order, but rather analyse, synthesis and evaluate in a more rapid cycle, almost simultaneously. In many cases, it is only after a designer synthesises a solution that he or she is able to create important design requirements. Lawson (1990) called this phenomenon "analysis through synthesis".

For the same reason, designers cannot do without drawing sketches during a conceptual design stage. It is not until externalizing on paper what might be a potential solution that a designer is able to see new relations and features in it and thereby obtain clues for important aspects of the problem (Robbins, 1992). Our previous study of design sketches presented evidence which suggests that designers' thoughts of functional issues in an architectural design task occur by being situated in the acts of drawing and perceiving visual/spatial features of the depictions (Suwa, Gero, and Purcell, 1998).

Then, a question arises. What kinds of cognitive interaction with his or her own sketches allow a designer to create important design requirements? More precisely, what actions in drawing sketches and inspecting them constitute the creation of design requirements? Or, what actions tend to cause the creation of design requirements? We will address these issues in this paper.

We examined the cognitive processes of a practising architect using a protocol analysis technique. Our coding scheme (Suwa, Purcell, and Gero, 1998) enables the coding of different modes of a designer's cognitive actions: drawing, paying attention to the existence of depictions, perceiving visual/spatial features of depictions, associating features with meanings or functional issues, and setting-up goals etc. The actions of creating design requirements were identified as the set-up of goals belonging to certain classes. Our examinations in this paper focused on whether or not particular types of actions tend to co-occur with, or prefigure, the creation of design requirements. In the second section, we will review the basic ideas of our coding scheme. We will present the results in the third section, and discuss their significance and implications in the fourth section.

2. Protocol Analysis

2.1 Protocol Data

The protocols of the design session of the practising architect were collected as a retrospective report after the session (Suwa and Tversky, 1997). The design session, which lasted for 45 minutes, was to work on the conceptual design of a museum on a given site in the suburb of a large city. The architect was encouraged to draw sketches on tracing paper. His sketching activities were videotaped. In the report session, he described, while watching the videotape, what he had been thinking of for each stroke of his pencil during the design session.

2.2 Coding Scheme: Overview

2.2.1 Segmentation

As many previous protocol analysis methods have done, we divide the entire verbal protocol into small units, that is, segmentation. The method of segmentation we employed is to divide the protocol based on the shift of subject's intention, of the contents of their thoughts, and of their actions (e.g. Goldschmidt, 1991; Van Someren et. al, 1994; Suwa & Tversky 1997; Gero & McNeill, 1998).

2.2.2 Different modes of cognitive actions

For each segment, we code different modes of designers' cognitive actions. There are four modes: physical, perceptual, functional and conceptual. The first category, **physical,** refers to actions that have direct relevance to physical depictions on paper. It consists of two classes: drawing-actions and looking-actions. We call the former D-actions, and the latter L-actions.

D-actions are divided into two classes. One is to draw a new element on paper. We call this class D_{new}-actions. Designers draw various types of depictions, such as circles, lines, rectangles, arrows and so on, to represent architectural functions and/or areas. We segment fluid drawing strokes into instances of separate D-actions, using the following principle; we interpret as a single action a chunk of strokes which the designer intended to be of one meaning. For this interpretation, we employ not only the designer's videotaped sketching activities but also the contents of his or her report about the corresponding depictions. The other class of D-action is to overdraw, or trace on another sheet, a previously-drawn element. The act of overdrawing or tracing on a single element, whether consisting of multiple or single strokes, is coded as a single action. We call this class D_{old}-actions.

L-actions are to pay attention to the existence of a previously drawn element, without any involvement of D-actions. We seek justification for L-actions, by interpreting the contents of the verbal protocol in terms of which elements the designer is talking about.

The second category, **perceptual**, refers to actions of attending to visual/spatial features of depicted elements. We call these P-actions. There are four types of P-actions: perceptions of (1) visual features of elements, such as shapes, sizes, or textures, (2) spatial relations among elements, such as proximity, remoteness, alignment, intersection, connectedness and so on, (3) organisational relations or comparison among elements, such as grouping, uniformity/similarity, contrast/difference, and (4) implicit spaces that exist in-between depicted elements. We collect instances of P-actions from verbal protocols, interpreting the semantic contents of the protocol.

Orthogonally to the categorisation into the four types, P-actions are divided into two classes. One is the action to perceive a new visual/spatial feature; it is a first-time perception of the particular feature during the process. The other is the action to re-mention a previously-attended feature. We call the former P_{new}-action, and the latter P_{old}-action. This dichotomy applies to all the four types of P-actions; P-actions belonging to each type could be P_{new}- or P_{old}-action. For example, if a designer perceives a proximity between two areas in the sketch for the first time, it is a P_{new}-action belonging to the second type. If a designer re-attends to an alignment of three depictions which he or she has attended to before, it is a P_{old}-action belonging to the second type.

P_{new}-actions, in turn, are divided into two subclasses. One is to perceive a new visual/spatial feature of previously-depicted element(s). For example, if a designer for the first time perceives a proximity between two previously-depicted elements, this perception belongs to this subclass. In general, representing something externally on paper forces some specificity and organization (Stenning and Oberlander, 1995). Once a designer depicts elements on paper, the representation comes to possess many visual/spatial features. However, the designer usually is not aware of all of them, rather intend only some of them when he or she made the depictions. It is not until when he or she inspects the representation later that the designer becomes aware of many unintended features. This is the action of discovering hidden features in sketches in an unexpected manner (Goldschmidt, 1994; Suwa, Gero, and Purcell, 1999). We denote actions belonging to this subclass as P_{uxd}.

The other subclass of P_{new}-actions is to perceive a new visual/spatial feature of element(s) one of which at least is being newly made. For example, if a designer draws a new element near an existing element, attending to a proximity between the two, then the perception of the proximity belongs to this class. As another example, if a designer draws a new element and at the same time intentionally gives a certain shape to the element, the perception of the shape belongs to this class. This is the action of intentionally creating a new visual/spatial feature. We denote actions belonging to this subclass as P_{cre}.

The third category, **functional**, refers to actions of associating depicted elements or their visual/spatial features with meanings, functional issues or abstract concepts. This category, however, is not relevant to the purpose of this paper.

The fourth category, **conceptual**, refers to higher cognitive actions, such as the set-up of goals, preferential or aesthetic evaluations, and the retrieval of knowledge or past similar cases. Out of these three, the set-up of goals is relevant to the purpose of this paper; the creation of design requirements appear in protocols as the act of setting up goals to bring them into reality. We will describe the coding of goals in the subsequent section.

2.3 The Coding of the Creation of Design Requirements

Our previous research (Suwa, Gero, and Purcell, 1999) classified into several types goals which designers set up during the design process. Table 1 summarises all the types. There are four major types: goals to introduce a new function (Type 1 goals), goals to introduce a function as a solution to a problematic conflict in the current design (Type 2 goals), goals to apply a previously-introduced function in the current context (Type 3 goals), and repeated goals from a previous segment (Type 4 goals).

Type 1 goals are, in turn, divided into several subclasses. The first subclass is a goal to create, in a new spot in the sketch, a function listed in the initial requirements given to the designer (Type 1.1). The second is a goal to introduce a new function as prescribed by a piece of knowledge or a past similar case (Type 1.2). The third is a goal extended from a previous goal. One form of extension is to add a more concrete specification to the function which the previous goal dictated. Another form of extension is to generalise the issue dealt with in the previous goal and bring it into a broader context. The fourth is a goal to create a new function in a way that is not supported by initial requirements, knowledge, or previous goals (Type 1.4). When there is no evidence in the verbal protocol as to how the architect conceived of the goal, we code it into Type 1.4.

Table 1. Types of goals to invent new functions and issues

Type 1: goals to introduce new functions	
Type 1.1:	based on the given list of initial requirements
Type 1.2:	as prescribed by explicit knowledge or past cases
Type 1.3:	as a extension from a previous goal (subtypes: specifying & broadening)
Type 1.4:	in a way that is not supported by knowledge, given requirements, or a previous goal
Type 2: goals to introduce functions as solutions to problematic conflicts	
Type 3: goals to apply previously introduced functions or arrangements in the current context	
Type 4: repeated goals from a previous segment	

Which types of goals should be interpreted as instances of "the creation of design requirements by the designer himself"? This has the connotation that the requirement created is at least a novel one. Therefore, Type 3 and Type 4 goals should not be regarded as the instances. Further, it has the connotation that the originality of the requirement created belongs to the designer; the designer creates it as a result of understanding important aspects of the given problem from his or her own viewpoint. Therefore, Type 1.1 goals, which are set up based on the initial requirements given to the designer, should not be regarded as the instances. Thus, we interpret the summation of Type 1.2, Type 1.3, Type1.4 and Type 2 goals as instances of the creation of design requirements, although the four types differ in the ways in which design requirements are created. We denote goals for the creation of design requirements as G_{dr}.

3. Results

3.1 The coding of D-, L-, and P-actions

The entire protocol of our architect contained 340 segments. For each segment, we coded instances of different modes of his cognitive actions. The entire protocol contained 350 D-actions, 581 L-actions, and 606 P-actions. Out of 350 D-actions, 272 belonged to D_{new}, and 78 to D_{old}. Out of 606 P-actions, 393 belonged to P_{new}, and 213 to P_{old}. Out of 393 P_{new}-actions, 222 belonged to P_{cre}, and 171 to P_{uxd}. Table 2 summarises these results.

Table 2: the frequencies of cognitive actions

category	frequency		
D-actions:	350		
Dnew: make new depictions		272	
Dold : overdraw, trace		78	
L-actions:	581		
P-actions:	606		
Pnew: perceive new features		393	
Pcre: create new features			222
Puxd: discover hidden features			171
Pold: re-mention previous features		213	

3.2 The Coding of Goals for Creation of Design Requirements"

The entire protocol contained 237 instances of the set-up of goals. Table 3 shows the number of occurrences of each type of goal. We had 122 instances of goals for the creation of design requirements (G_{dr}), i.e. the sum total of Type 1.2, Type 1.3, Type 1.4, and Type 2. This corresponds to 51.5% of the total occurrences of goals. The fact that about a half of the goals relate to the act of creating novel design requirements suggests its importance in the design process of this architect. Further, G_{dr} was about 4 times as frequent as Type 1.1 goals to introduce new functions based on the given list of requirements, 122 vs. 32. This is clear evidence, as we discussed in the introduction, that designers not just satisfy initially given requirements but, more importantly, create novel design requirements during the process by themselves.

TABLE 3. The numbers of occurrences of distinct types of goals

Types	Number of goals identified	Percentage to the total (%)
Type 1.1	32	13.5
Type 1.2	37	15.6
Type 1.3	43	18.1
Type 1.4	28	11.8
Type 2	14	5.9
Type 3	52	21.9
Type 4	31	13.1
G_{dr} (Type 1.2 + Type 1.3 + Type 1.4 + Type 2)	122	51.5
total	237	

3.3 The Relation between the Occurrences of G_{dr} and Those of D-, L- or P-Actions

We examined whether or not particular action(s) out of D-, L- and P-actions are strongly related to the occurrences of G_{dr}. The basic idea of the examination is as follows. The occurrences of a particular type of actions, i.e. D-, L- or P-actions, are not distributed evenly to all the segment, but dense in some segments and sparse in others. For example, many P-actions could occur in each of some segments, while no P-action in others. Thus, if a dense population of a particular type of actions is likely to co-occur with and/or prefigure the occurrence(s) of G_{dr}, then we are able to conjecture that G_{dr} occurs in strong relation to the occurrences of this particular type of actions.

We will explain this, taking as an example the examination of whether or not G_{dr} occurs in strong relation to P-actions. First, we determine the threshold frequency, T, of a "dense population" of P-actions as follows. We calculated the average occurrences per segment, Avg, and its standard deviation, σ. If $Avg+\sigma$ is larger than 1, rounding off $Avg+\sigma$ makes T. If $Avg+\sigma$ is smaller than 1, T is set to 1. Table 4 shows Avg, σ, $Avg+\sigma$, and T, for each type of action. Since $Avg+\sigma$ for P-actions is 2.90, T for P-actions is 3. If three or more than three P-actions occur in a single segment, this segment is regarded as one with a "dense population" of P-actions.

Table 4: The statistics of occurrences of each type of cognitive actions per segment

cognitive actions	average (Avg)	standard deviation (σ)	Avg + σ	threshold of a dense population (T)
D-actions	1.03	0.87	1.90	2
L-actions	1.71	1.04	2.75	3
P-actions	1.78	1.12	2.90	3

Second, we classify the entire segments, i.e. 340 segments, into the following four classes in terms of the occurrence of a "dense population" of P-actions:

(1) class 1: segment which has a dense population of P-actions, but whose immediately previous segment has no dense population of P-actions (we call this "with but not next of a dense population"),

(2) class 2: segment which has no dense population of P-actions, but whose immediately previous segment has a dense population of P-actions (we call this "next of but not with a dense population"),

(3) class 3: segment which has a dense population of P-actions, and whose immediately previous segment also has a dense population of P-actions (we call this "next of and with a dense population"),

(4) class 4: the remaining segment; segment which has no dense population of P-actions, and whose immediately previous segment, either, has no dense population of P-actions (we call this "other").

If the frequent occurrences of P-actions have no strong relation to G_{dr}, the occurrences of G_{dr} would be distributed to each class of segments in proportion to the ratio of the number of each class to the total. If there is a strong relation, more instances of G_{dr} would be distributed to particular classes of segments.

Table 5 shows the number of segments belonging to each class and the occurrences of G_{dr} at each class of segments. The difference from the expected occurrences at each class of segments, which is calculated from the ratio of the number of segments belonging to each class to the total number of segments, is also shown. The distribution of instances of G_{dr} over the four classes of segments is unequal, although this tendency is statistically not strong, $\chi^2(3) = 7.64$ ($p=0.06$); more instances of G_{dr} occurred in class 1 segments, and less in class 2 segments. Then, as shown in Table 6, we combined segments belonging to class 1 and class 3 into a single class, and segments belonging to class 2 and class 4 into another. The former is the class of segments in which the population of P-actions is dense, while the latter is the class of segments in which the population of P-actions is not dense. More instances of G_{dr} occurred, in a statistically significant manner, in segments in which the population of P-actions is dense, $\chi^2(1) = 6.24$ ($p<0.025$). In other words, G_{dr} is likely to co-occur with a dense population of P-actions.

Note that, if we combine class 2 and class 3 segments, the occurrences of G_{dr} at segments belonging to the merged class are less frequent than the expected value. The merged class corresponds to immediately the next segment of a segment which has a dense population of P-actions. This indicates that a dense population of P-actions does not prefigure the occurrences of G_{dr}. In other words, it is not necessarily the case that there is a causality from intensive occurrences of P-actions to Gdr.

TABLE 5. The occurrences of G_{dr} in the four classes of segments categorised in relation to the occurrences of a dense population of P-actions

		G_{dr}	
classes of segments in terms of a dense population of P-actions	number of segments	number of occurrences	difference from the expected value
class 1: with but not next of	56	29	+9.0
class 2: next of but not with	56	13	- 7.0
class 3: next of and with	23	11	+2.6
class 4: other	205	69	- 4.6
total	340	122	

statistical test of distribution			weak ($\chi^2(3)$ = 7.64, p=0.06)

TABLE 6. The occurrences of G_{dr} in the combined classes of segments categorised in relation to the occurrences of a dense population of P-actions

classes of segments	number of segments	G_{dr} number of occurrences	G_{dr} difference from the expected value
class 1 +c lass 3: P-actions are dense	79	40	+11.6
class 2 + class 4: P-actions are not dense	261	82	- 11.6
total	340	122	
statistical test of distribution			strong ($\chi^2(1)$ = 6.24, p<0.025)

Likewise, we carried out the same examination for D-actions, and for L-actions. As shown in Table 4, the threshold frequency of a dense population is 2 for D-actions, and 3 for L-actions, respectively. As far as D-actions are concerned, instances of G_{dr} were not unequally distributed over the four classes classified in relation to a dense population of D-actions, $\chi^2(3) = 0.88$ (p>0.75). Further, no matter how we combined classes of segments, we did not find in a statistically significant way an unequal distribution of G_{dr}. As far as L-actions are concerned, instances of G_{dr} were not unequally distributed over the four classes classified in relation to a dense population of L-actions either, $\chi^2(3) = 0.76$ (p>0.75). Further, no matter how we combined classes of segments, we did not find in a statistically significant way an unequal distribution of G_{dr}. These results suggest that G_{dr} occurs neither in relation to dense occurrences of D-actions, nor to those of L-actions.

3.4 The Relation between the Subclasses of P-actions and G_{dr}

The examination in the preceding section has indicated that the occurrences of G_{dr} are strongly related to intensive occurrences of P-actions. Then, the following question arises. Do all types of P-actions involve this relationship in similar ways? Or particular types of P-actions only? Given that P-actions are divided into P_{new}-actions and P_{old}-actions, we examined the relation between the occurrences of each type of P-actions and those of G_{dr}.

TABLE 7. The occurrences of G_{dr} in the four classes of segments categorised in relation to the occurrences of a dense population of P_{new}-actions

classes of segments in terms of a dense population of P_{new}-actions	number of segments	G_{dr} number of occurrences	G_{dr} difference from the expected value
class 1: with but not next of	63	38	+15.4
class 2: next of but not with	63	20	- 2.6
class 3: next of and with	48	15	-2.2
class 4: other	166	49	- 10.6
total	340	122	
statistical test of distribution			strong ($\chi^2(3)$ = 12.9, p<0.005)

The average occurrences of P_{new}-actions per segment and its standard deviation were 1.16 and 1.04. Therefore, the threshold frequency of a dense population of P_{new}-actions is 2. Table 7 shows the number of segments belonging to the four classes categorised in relation to a dense population of P_{new}-actions as well as the occurrences of G_{dr} at each class of segments. Instances of G_{dr} are partially distributed to class 1 segments, $\chi^2(3) = 12.9$ ($p<0.005$). When we combine class 1 and class 3 segments into a single class, and class 2 and class 4 segments into another, the distribution of G_{dr} over the two combined classes is statistically unequal, $\chi^2(1) = 6.46$ ($p<0.025$); more instances of G_{dr} are likely to occur at segments in which the population of P_{new}-actions is dense (class 1+ class 3). This indicates that G_{dr} was likely to co-occur with intensive occurrences of P_{new}-actions. Further, if we combine class 2 and class 3 segments, the occurrences of G_{dr} at segments belonging to the merged class are less frequent than the expected value. This indicates that it is not necessarily the case that there is a causality from intensive occurrences of P_{new}-actions to Gdr.

On the other hand, the average occurrences of P_{old}-actions per segment and its standard deviation were 0.63 and 0.88. Therefore, the threshold frequency of a dense population of P_{old}-actions is 2. We examined how many instances of G_{dr} occurred at each of the four classes categorised in relation to a dense population of P_{old}-actions. We found that the distribution of instances of G_{dr} over the four classes was not statistically unequal, $\chi^2(3) = 2.46$ ($p=0.5$). Further, no matter how we combined classes of segments, we did not find in a statistically significant way an unequal distribution of G_{dr}. This suggests that G_{dr} occurs in no relation to a dense population of P_{old}-actions.

3.5 The Relation between the Subclasses of P_{new}-actions and G_{dr}

As we described in section 2.2, P_{new}-actions are further divided into two types. One is the action of intentionally creating a new visual/spatial feature, i.e. P_{cre}. The other is the action of discovering hidden features in sketches in an unexpected manner, i.e. P_{uxd}. We examined whether both types of P_{new}-actions account for the strong relationship between P_{new}-actions and G_{dr}, or only one of them.

TABLE 8. The occurrences of G_{dr} in the four classes of segments categorised in relation to the occurrences of a dense population of P_{cre}-actions

		G_{dr}	
classes of segments in terms of a dense population of P_{cre}-actions	number of segments	number of occurrences	difference from the expected value
class 1: with but not next of	74	42	+15.4
class 2: next of but not with	74	18	- 8.6
class 3: next of and with	79	31	+2.7
class 4: other	113	31	- 9.5
total	340	122	
statistical test of distribution			strong ($\chi^2(3) = 14.2$, $p<0.005$)

The average occurrences of P_{cre}-actions per segment and its standard deviation were 0.65 and 0.80. Therefore, the threshold frequency of a dense population of P_{cre}-actions is 1; this means that even a single occurrence of P_{cre}-action at a segment is regarded as a dense population. Table 8 shows the number of segments belonging to the four classes categorised in relation to a dense population of P_{cre}-actions as well as the occurrences of G_{dr} at each class of segments. Instances of G_{dr} are partially distributed to class 1 segments, $\chi^2(3) = 14.2$ ($p<0.005$). When we combine class 1 and class 3 segments into a single class, and class 2 and class 4 segments into another, the distribution of G_{dr} over the two combined classes is statistically unequal, $\chi^2(1) = 10.84$ ($p<0.005$); more instances of G_{dr} are likely to occur at segments in which the population of P_{cre}-actions is dense (class 1+ class 3). This indicates that G_{dr} was likely to co-occur with intensive occurrences of P_{cre}-actions. Further, if we combine class 2 and class 3 segments, the occurrences of G_{dr} at segments belonging to the merged class are less frequent than the expected value. This indicates that it is not necessarily the case that there is a causality from intensive occurrences of P_{cre}-actions to Gdr.

On the other hand, the average occurrences of P_{uxd}-actions per segment and its standard deviation were 0.50 and 0.72. Therefore, the threshold frequency of a dense population of P_{uxd}-actions is 1. We examined how many instances of G_{dr} occurred at each of the four classes categorised in relation to a dense population of P_{uxd}-actions. We found that the distribution of instances of G_{dr} over the four classes was not statistically unequal, $\chi^2(3) = 0.25$ ($p>0.9$). Further, no matter how we combined classes of segments, we did not find in a statistically significant way an unequal distribution of G_{dr}. This suggests that G_{dr} occurs in no relation to a dense population of P_{uxd}-actions.

P_{cre}-actions, in definition, fall into either of two types: one is to perceive a spatial or organisational relation between new depiction(s) and existing depiction(s), and the other is to perceive a visual feature of a newly depicted element, such as its shape, size or texture. Therefore, P_{cre}-actions necessarily involve making new depictions, D_{new}-actions, within the same segment. Then, the following question arises. Given that G_{dr} is likely to co-occur with a dense population of P_{cre}-actions, does it co-occur with a dense population of Dnew, too? The result was as follows. The average occurrences of D_{new}-actions per segment and its standard deviation were 0.80 and 0.77, and therefore, the threshold frequency of a dense population of Dnew-actions is 2. We examined how many instances of G_{dr} occurred at each of the four classes categorised in relation to a dense population of D_{new}-actions. We found that the distribution of instances of G_{dr} over the four classes was not statistically unequal, $\chi^2(3) = 3.20$ ($p>0.25$). When we combined class 1 and class 3 segments into a single class, and class 2 and class 4 segments into another, the distribution of instances of G_{dr} over the two combined classes was slightly unequal but not up to statistical significance, $\chi^2(1) = 3.10$ ($p<0.1$). This suggests that a dense population of D_{new}-actions does not necessarily suggest the likelihood of the co-occurrence of Gdr.

4. Discussions and Implications

4.1 Significance of Acts of Creating New Visual/Spatial Features

Our finding is that P-actions, especially actions of creating new visual/spatial features (P_{cre}), is likely to co-occur with, but not prefigure, the creation of novel design requirements. How should we interpret this? It does not mean that creating new visual/spatial features is likely to cause novel design requirements to be created. There are two reasons. First, a dense population of P_{cre} did not necessarily tend to prefigure the occurrences of G_{dr}. Second, the present analysis based on segmentation is not so detailed as to reveal causalities between actions that co-occur in the same segment; the co-occurrence of two distinct types of actions in a segment assures no more than the fact that the two types of actions happened simultaneously. Further, for the very second reason, our finding does not mean, either, that the creation of novel design requirements is likely to cause P_{cre}-actions.

Rather, our finding means that perceptual actions of creating visual/spatial features *constitute* the creation of novel design requirements as its key component. This suggests the significance of two types of perceptual actions in a design process: one is to perceive a spatial or organisational relation between new depiction(s) and existing depiction(s), and the other is to perceive a visual feature, such as shape, size or texture, of a new depiction.

In spite of the fact that a dense population of P_{cre}-actions is likely to co-occur with G_{dr}, and that P_{cre}-actions always involve D_{new}-actions in the same segment, a dense population of D_{new}-actions did not necessarily constitute the creation of novel design requirements. This suggests the following; no matter how actively a designer draws new elements on paper, it will not necessarily lead to the creation of novel design requirements, unless the acts of drawing are accompanied by perception of new features, either relations or visual features. For example, just depicting something new on paper by intending it to represent an architectural function, e.g. pond, does not suffice to create novel design requirements. Rather, paying active attention to a spatial relation which the new depiction will establish against existing depictions, and associating the new relation with a functional issue may contribute to the creation of a novel design requirement.

Likewise, just attention to the existence of previously-depicted elements, i.e. L-actions, does not contribute to the creation of design requirements. Active perception of revisiting previously-attended visual/spatial features, i.e. P_{old}-actions, does not, either.

4.2 Situated View of Designing

In cognitive science, there has been a prevailing view that human cognition is a situated act (e.g. Clancey, 1997). This applies to designing as well; designers construct design ideas on the fly in a situated way, responding to visual/spatial features of the physical setting in which they sketch (Gero, 1998; Suwa, Gero and Purcell, 1998). The present finding is supportive evidence of this. We will explain why. The occurrences of P_{cre}-actions during a design process is entirely dependent on what the designer has depicted so far, and thus on what kinds of configuration of depicted elements the designer sees in front of him or her. In this sense, no designer is able to foresee what kinds of visual/spatial features he or she will create at future stages of his or her design process; rather, the designer is able to create new relations and visual features only by perceptually interacting with the present configuration of hie or her sketches. Given our finding that intensive occurrences of Pcre-actions are a key constituent of the creation of design requirements, therefore, we can deduce the following; the creation of novel design requirements occurs on the fly in a situated way, being entirely dependent on what the designer has so far sketched and what he or she is able to perceive at the very moment.

4.3 Implication for Design Education

As we discussed in the introduction, creating novel design requirements during the process is one of the necessary actions to make a design process successful. How should novice designers be taught to do this? The present finding has a pedagogical implication for this. It suggests the significance of *conscious efforts to establish new relations and introduce new visual-features in the sketch*. This advice may reveal its usefulness only through repeated practice in actual design assignments which novice designers are provided with. Due to the situated aspect of designing through sketching, it would be impossible to prescribe what kinds of "relations and visual features" novice designers should attend to or create during the process. Depending on design assignments and on how and what elements each novice designer will sketch, different kinds of "new relations and visual-features" could emerge. Novice designers themselves should always sensitively attend to the potential of new relations and visual features in their own sketches and thereby associate those visual/spatial features with functional issues. Perceptual attitudes of this sort may enable them to conceive of novel design requirements.

Conclusion

Designers not just synthesise solutions that satisfy initially given requirements, but more importantly, create novel design requirements by themselves during a conceptual design process. We focused on the latter acts as one of the key actions in design thinking. The question we raised was how practising architects are able to create novel requirements during the process.

To examine this, we employed the technique of retrospective protocol analysis. Our coding scheme of protocols enables the coding of different modes of a designer's cognitive actions: drawing (D-actions), looking at previously-depicted elements (L-actions), perceiving visual/spatial features (P-actions), associating features with meanings (F-actions), higher cognitive actions (C-actions), such as the set-up of goals. We found that the acts of creating novel requirements are identified as the set-up of goals belonging to certain classes. Thus, we examined whether particular types of actions out of D-, L- and P-actions tend to co-occur with, and/or prefigure, the occurrences of goals for the creation of requirements.

We have obtained the following findings. Intensive occurrences of a certain type of P-actions, i.e. acts of creating new relations or visual features, were likely to co-occur with, but not prefigure, the creation of requirements. This means that this type of P-actions are the central constituent of the creation of novel design requirements. Further, the creation of requirements had no relation to intensive occurrences of D-, L- or any other types of P-actions. These findings suggest how the practising architect created novel design requirements; neither making depictions nor inspecting previously-depicted elements, no matter how active they were, led the architect to the creation of design requirements. It is only when those actions involved establishing new relations or creating visual features on the sketch that the architect were able to create novel requirements. This suggests the significance of acts of establishing new relations or creating new visual features in sketching activities. It has a pedagogical implication, providing insight about how to cognitively interact with sketches.

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