

# Common Design Elements and Strategies in Participatory Safety Sign Redesign among Construction Workers

Annie W.Y. Ng and Alan H.S. Chan

**Abstract**—This study investigated the mental models of construction workers on safety sign representations in participatory sign redesign. Twenty-three Hong Kong Chinese construction workers were asked to draw different safety sign referents and to narrate their drawings and redesign ideas. The drawings for each sign referent were assessed. It was revealed that the participants spontaneously divided the sign referents into components and portrayed the referents component by component. Four mental models on sign representation for referents were identified. The model of *Complete and incomplete referents* had a significant influence in participatory sign redesign, and the extent of agreement among workers on representation for incomplete referents was not easily reached. The model of *Action words* were expressed by portraying the results of an action or the situation that such kind of action would happen, and the graphical representations of the actions were concrete images of the tools used to realize the actions. The models of *Prohibition and signal words* were generally expressed through surround shapes but the choice of surround shapes seemed to be arbitrary. These results increased our understanding of the design rationale and justification and how the complete representation was built in sign redesign among construction workers. The findings help facilitate the process and practice of the user-involved participatory safety sign redesign in future.

**Index Terms**—safety sign, construction worker, participatory design, graphical representation

## I. INTRODUCTION

CONSTRUCTION safety has been a growing concern in recent years in Hong Kong, as the construction industry has been recorded as having the highest number of fatalities and highest accident rate among all industry sectors for seven consecutive years [1]. There are a number of possible safety precaution measures that can be taken to reduce accidents and injuries in workplaces. Provision of suitable and relevant safety signs is one of the significant safety precaution and guidance measures that can be implemented quickly to promote safety awareness and develop a safety and health culture on construction sites [2].

However, construction personnel in Hong Kong were found to have substantial problems in comprehending safety signs that are posted on construction sites; the signs should be

redesigned so as to improve their effectiveness and the safety message conveyed [3]. Some research studies suggested as to when and how safety sign redesign should be carried out [4, 5], and reached a consensus that strategies on safety sign redesign should be based on the consideration of user perceptions and evaluation feedback.

To better address user needs and preferences and to create successful human factors and ergonomics design, there is a need to involve users in the design process. With user participation in the process of graphic sign design, the signs would be more likely to be correctly interpreted as having the intended meanings because the signs were more likely to directly map onto the mental models of users [6, 7]. One of the user-involved design methods for graphic sign design is called stereotype production method [7–12, 17]. This method requires a group of representative users to draw pictorials that best express the sign referent of interest, i.e. the message that a sign is intended to convey. The population stereotype, which is the most common pictorial element generated for the referent, is then passed to graphic designers to render into an actual sign.

This study was conceived and designed to increase understanding of the design rationale and justification for design decisions made and how the complete representation was built throughout participatory safety sign redesign process among construction workers. The results should help the optimization of participatory safety sign redesign, and thus facilitate the process and practice of sign redesign with user involvement in future.

## II. METHOD

### A. Participants

Twenty-three Hong Kong Chinese male construction workers aged between 18 and 59 years (mean = 31.5 years, standard deviation = 8.5 years) participated in the study. They all worked in the construction industry at the time of the study as site labourers, bricklayers, inspectors of works, plant and equipment operators, concreters, excavators, carpenters, bamboo scaffolders, electrical fitters, and welders.

### B. Sign Referents

Twenty-four commonly used Hong Kong industrial safety signs were found at a comprehension level of less than 75% [4]. Half of these sign referents were randomly selected for examination in this study (Table 1).

### C. Apparatus

A touch screen tablet personal computer with dual core 1

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GHz processor and 7-inch monitor (Samsung GALAXY TAB 2.7.0) was used for the study. An application program (Scribble!) was installed and provided participants with the means to draw and save their drawings.

D. Procedure

For each sign referent, the participants were asked to draw the first picture that came into mind as quickly as possible in the tablet personal computer using colors that they preferred. Eleven colors: red, yellow, grey, blue, pink, black, white, green, purple, sky blue, and dark green were available for the participants to use. The participants had to keep their drawings as simple as possible, to draw each picture as large as possible in the whole screen size of the 7-in monitor, and to avoid using letters, words and numerals in their drawings. They were also required to verbally describe and explain their drawings.

III. RESULTS

All the construction workers in this study could visualize and illustrate each safety sign referent pictorially. A total of 276 drawings (12 safety sign referents x 23 participants) were collected in this study. Fig. 1 shows some of these drawings. For each referent the drawings were reviewed and sorted into categories according to drawings that used the same kinds of pictorial elements. The transcribed verbal descriptions helped to further understand the meanings the participants wished to convey in the drawings.

Table 1 summarizes the proposed design pictorial elements for each sign referent. We found that the participants by and large divided a referent into two to four components and then illustrated the referent component by component. The component representations corresponded with real objects with which the participants were familiar with. For instance, referent R9 (Emergency exit) was split into two components “emergency” and “exit”. “Exit” was represented as a door or

a road and “emergency” was expressed with a running human figure, exclamation mark, red fire, or directional pointing arrow, thus leading to a number of pictorial content compositions and design ideas including “human figure running to the door”, “an arrow pointing to the door”, “human figure running to the door and an exclamation mark”, “red fire near the door”, and “human figure is running on the road”. Analysis of pictorial suggestions by the participants also showed their mental models on sign representations for various kinds of referents: (i) complete vs. incomplete referents, (ii) referents with action words, (iii) referents with signal words, and (iv) referents with prohibition words.

A. Complete Referents vs. Incomplete Referents

Designs that had the same pictorial elements were recognized as having a similar design idea. The number of design ideas per referent ranged between 7 (F10 – Caution! Slippery surface) and 14 (R4 – No playing; R5 – Do not operate). Referents had a significant effect on the number of design ideas (ANOVA,  $F_{[1, 11]} = 10.519, p = 0.009 < 0.05$ ). The mean number of design ideas for complete referents (R3, R7, R8, R9, R10 & R12; mean = 9.17 & standard deviation = 1.72) was significantly less than that for incomplete referents (R1, R2, R4, R5, R6 & R11; mean = 12.17 & standard deviation = 1.47). Referents R1, R2, R4, R5, R6 and R11 were categorized as incomplete as it was not clearly or explicitly specified in these referents what type of moving machine, what kind of danger and harmful, the nature of playing, what is being operated, what is being touched, and mind your hands for what. The less incomplete the referent, the number of design ideas increased significantly. Details of the pictorial suggestions for each of the incomplete referents are as follows.

For referent R1 (Caution! Moving machine can crush hand), the kind of moving machine was not specified. 22 participants drew gear, pressing machine, or electric drill. One participant did not illustrate the machine out and drew “hand and a cross”.

For referent R2 (Danger! Harmful), the kind of danger and harmful was not specified. One participant drew a bottle of chemicals. Another participant imagined the danger and harmful were on the hand and illustrated the referent as “hand and a cross inside the triangle”. Others expressed the referent by using cross, skull, and/or exclamation mark pictorials.

For referent R4 (No playing), the nature of the ‘playing’ was not specified in the referent. The participants conceived ‘playing’ as cycling, football, basketball, running, or playing with merry-go-round, slide or swing, and ‘no’ was expressed as a cross, slash, and/or triangular bounded shape, thus leading to various pictorial content compositions and design ideas.

For referent R5 (Do not operate), what is being operated was not mentioned in the referent. 21 participants drew a button, joystick, on-off switch, screwdriver, spanner, control, or wheel control. Two participants did not mention anything related to “operate” in the drawings; they simply drew “hand and a red cross” and “hand and a slash inside the circle” to illustrate the referent.

For referent R6 (Do not touch), what is being touched was not mentioned in the referent. Less than half (10) of the

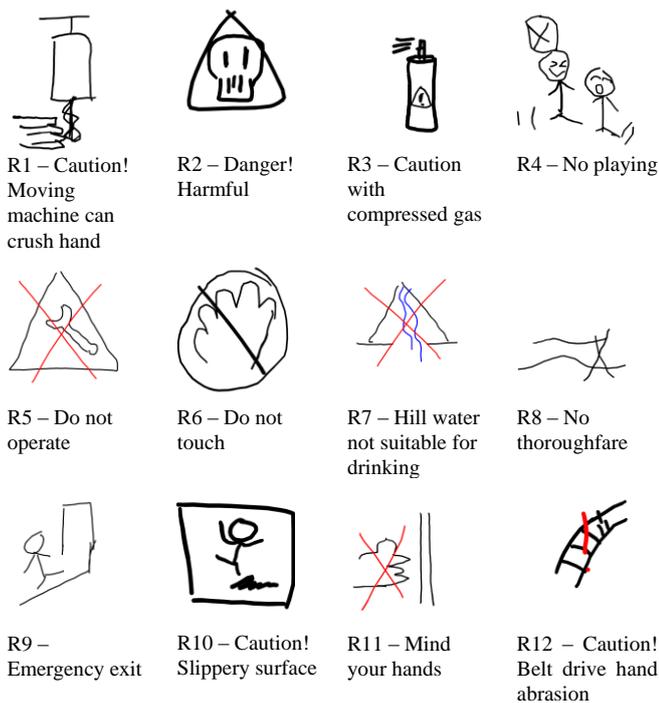


Fig. 1. Some safety sign designs from construction workers.

participants illustrated with a button, sharp tool, fire, machine, a bottle of chemicals, or electric.

For referent R11 (Mind your hands), mind your hands for what was not specified. Eighteen participants drew a door gap or a pressing machine and the remaining five participants illustrated the referents as “examination mark on a hand” and “hand of a human figure is being hurt”.

### B. Action Words

The action words such as “crush”, “playing”, “operate”, “touch” and “drinking” that conveyed an action or a state of being were found in R1 (Caution! Moving machine can crush hand), R4 (No playing), R5 (Do not operate), R6 (Do not touch), and R7 (Hill water not suitable for drinking).

For referent R1 (Caution! Moving machine can crush hand), the action “crush” was expressed by showing the results of the action like “the hand bleeding red blood” or by showing the situation that such kind of “crush” would happen e.g. placing the hand under a pressing machine

For referent R4 (No playing), no participants directly addressed the action “playing” in their drawing. The participants drew what would be played instead such as a bike, football, basketball, running, merry-go-round, slide, or swing.

For referent R5 (Do not operate), no participants directly mentioned the action “operate” in their drawing. Almost all the participants (21 participants) illustrated something that would be operated in a construction site such as a button, joystick, on-off switch, screwdriver, spanner, control, and wheel control.

For referent R6 (Do not touch), almost all participants assumed that the action “touch” was done by “hand” or “finger” and thus drew “hand” and “finger”. Two participants did not address “touch” in the drawing. They simply drew “fire” and “red cross” to illustrate the referent.

For referent R7 (Hill water not suitable for drinking), the action “drinking” was illustrated by drawing a lip near water, a cup, a glass, or a human figure. But more than half of the participants (56%) did not mention such action and simply drew “no hill water” to illustrate the referent.

### C. Signal Words

The signal words such as “caution”, “danger” and “mind” with the intention of giving warning of hazards ahead were found in the test referents. “Caution” appeared in R1 (Caution! Moving machine can crush hand), R3 (Caution with compressed gas), R10 (Caution! Slippery surface), and R12 (Caution! Belt drive hand abrasion). It was represented by and large using exclamation mark, cross, slash, or triangular or square bounded shape. Some expressed “caution” by showing the results of an action described (e.g. hand bleeding red blood) in referents R1 and R12. For referent R3 – Caution with compressed gas, a participant expressed “caution” by drawing the danger that would happen due to compressed gas “cylinder exploded with red fire”. Some participants ignored the signal word and did not illustrate it in their drawings.

For referent R2 (Danger! Harmful), the signal word “danger” was illustrated with the use of exclamation mark, triangular or circular bounded shape, cross, and skull. For referent R11 (Mind your hands), the signal word “mind” was expressed as an exclamation mark or a cross. Two mentioned it by showing the results of a danger action like “hand

bleeding red blood”. But nine participants did not address “mind” in their drawings.

### D. Prohibition Words

Prohibition words such as “no (勿)”, “do not (禁止)”, and “not (不)” were used to indicate something must not be done and were found in R4 (No playing), R5 (Do not operate), R6 (Do not touch), and R7 (Hill water not suitable for drinking), and R8 (No thoroughfare). These wordings were expressed as “a cross”, “a slash”, and triangular bounded shape. One participant did not mention anything about “do not” for referent R6.

## IV. DISCUSSION

This study investigated the user mental models on sign representations for various kinds of referents: complete vs. incomplete referents, referents with action words, referents with signal words, and referents with prohibition words in participatory design with construction workers. The construction workers liked to split a sign referent into few components and portrayed the referent at the elemental level. The component representations corresponded with real objects and were closely related to the extent of daily exposure of the workers. A previous study by Goonetilleke et al. [13] indicated that the sign design of truly unified representations, which depict all elements of the function being represented, would lead to better sign recognition performance.

### A. Complete Referents vs. Incomplete Referents

Complete and incomplete referents had a significant influence on the number of design ideas in participatory sign design. Half of the referents in this study were incomplete, including referents R1 (Caution! Moving machine can crush hand), R2 (Danger! Harmful), R4 (No playing), R5 (Do not operate), R6 (Do not touch) and R11 (Mind your hands), as what type of moving machine, what kind of danger and harmful, the nature of playing, what is being operated, what is being touched, and mind your hands for what were not clearly and explicitly specified in these referents. The participants imagined and portrayed various graphical representations of moving machine (e.g. gear, pressing machine, electric drill), danger and harmful (e.g. a bottle of chemicals), nature of playing (e.g. cycling, football, basketball, running, merry-go-round, slide, swing), objects to be operated (e.g. button, joystick, on-off switch, screwdriver, spanner, wheel control), objects to be touched (e.g. sharp tool, fire, electric, pair of hands), and situations that need to be minded our hands (e.g. door gap, pressing machine) for these six referents respectively, leading to diverse pictorial compositions for each of these referents and a decrease of the extent of agreement among participants on the most common interpretation of the referents. Therefore, referents that are considered incomplete should be carefully addressed during the participatory design process. More specific descriptions about sign referents (e.g. additional contextual information) might be needed for users to participate fully in sign redesign.

### B. Action Words

The action words such as “crush”, “playing”, “operate”, “touch” and “drinking” were found in the test referents including R1 (Caution! Moving machine can crush hand), R4

TABLE I  
PROPOSED DESIGN PICTORIAL ELEMENTS FOR EACH SAFETY SIGN REFERENT

Referent	Design content
R1 - Caution! Moving machine can crush hand	Referent components: Caution + moving machine + can crush + hand - "Caution" was expressed as an exclamation mark or a cross. Some mentioned it by showing the results of the action "hand bleeding red blood". Some ignore this signal word and simply drew e.g. "hand and pressing machine" and "hand and electric drill". - The kind of moving machine was not explicitly specified in the referent. Some drew gear, pressing machine, or electric drill. Some did not draw the machine out and illustrate the referent as "hand and a cross". - "Crush" was expressed by showing the results of the action like "hand bleeding red blood" or by showing the situation that such kind of "crush" would happen e.g. placing the hand under a pressing machine. - "Hand": almost all the drawings consisted of "hand". One drew "finger" instead of "hand". Only one participant did not mention "hand" or any other parts of hand and he/she drew "gear and a red exclamation mark".
R2 - Danger! Harmful	Referent components: Danger + harmful - The kind of danger and harmful were not specified in the referent. One participant drew a bottle of chemicals. Another participant imagined the danger and harmful were on the hand and illustrated the referent as "The hand and a cross inside the triangle. Others expressed the referent by using cross, skull, and/or exclamation mark pictorials.
R3 - Cautions with compressed gas	Referent components: Caution with + compressed gas - "Caution" was represented using exclamation mark, cross, slash, or triangular bounded shape pictorials. One expressed it by drawing the danger that would happen due to compressed gas, "cylinder exploded with red fire". Five participants did not illustrate "caution" in the drawings and drew "cylinder contains compressed gas" or "compressed gas". - "Compressed gas" was commonly expressed by drawing a cylinder bottle.
R4 - No playing	Referent components: No + playing - "No" was expressed as "a cross", "a slash", and/or "triangular bounded shape". - What is being played was not mentioned in the referent. Participants drew a bike, football, basketball, running, merry-go-round, slide, or swing.
R5 - Do not operate	Referent components: Do not + operate - "Do not" was expressed as a cross or slash. - What is being operated was not mentioned in the referent. Twenty-one participants drew a button, joystick, on-off switch, screwdriver, spanner, control, or wheel control. The remaining two participants did not mention "operate" in their drawings; they simply drew "hand and a red cross" and "hand and circular with diagonal bar" to illustrate the referent.
R6 - Do not touch	Referent components: Do not + touch - "Do not" was expressed as a cross or slash, and almost all participants assumed that the action "touch" was done by "hand" or "finger" and thus drew "hand" and "finger". One participant did not mention anything about "do not" and two participants did not address "touch" in their drawings. They simply drew "fire" and "red cross" to illustrate the referent. - What is being touched was not mentioned in the referent. But most of the participants drew a button, sharp tool, fire, machine, a bottle of chemicals, electric, or pair of hands touch together.
R7 - Hill water not suitable for drinking	Referent components: Hill water + not suitable for + drinking - "Hill water" was expressed as 'a drop of water flowing from hill', 'water flowing from a hill' or 'water'. - "Not suitable for" was represented by a slash or a cross. - "Drinking" was illustrated by drawing a lip near water, a cup, a glass, and a human figure. 13 participants did not mention "drinking" in their drawings and illustrated "no hill water" only.
R8 - No thorough fare	Referent components: No + thorough fare - "No" was represented by a cross, a slash, and yellow banister. - "Thorough fare" was expressed by bridge, road, and door. - 15 participants did not address the referent component by component and the whole concept was represented by "fracture at end of road", "fracture in the middle of the road", "horizontal line inside a circle" or "human figure and circular with diagonal bar".
R9 - Emergency exit	Referent components: Emergency + exit - "Exit" was represented as a door or a road. - "Emergency" was expressed as "an arrow pointing to the door", "human figure is running and an exclamation mark near the door", "red fire near the door", or "red sign above the door". - One participant did not address the referent component by component; he/she illustrated the referent by drawing "green human figure inside a green circle".
R10 - Caution! Slippery surface	Referent components: Caution + slippery surface - "Caution" was expressed as an exclamation mark, triangular or square bounded shape, and "a notice in front of the human figure that is walking on the wet floor". One participant did not mention "caution" in their drawings and drew "foot on the wet floor". - Some illustrated "caution" by showing the results of the action on a slippery surface: i.e. human figure is falling. All participants imagined "slippery surface" as water.
R11 - Mind your hands	Referent components: Mind + your hands - Mind your hands for what was not specified. Some participants drew a door gap or a pressing machine, while some did not mention it. - "Mind" was expressed as an exclamation mark or a cross. Some mentioned it by showing the outcomes of a danger action like "hand bleeding red blood". But some participants did not address "mind" in their drawings and simply drew "hand is near the door gap". - "Hand" was illustrated by drawing a hand. But one participant did not mention it in the drawing and he/she drew "red exclamation mark is in the door gap".
R12 - Caution! Belt drive hand abrasion	Referent components: Caution + belt + hand + abrasion - "Caution" was mostly expressed as an exclamation mark or a cross. Five participants addressed it by illustrating the results of an action: "hand bleeding red blood". Eight participants did not mention "caution" in their drawings and drew "hand on conveyer belt". - All participants illustrated "belt" as "conveyer belt" or "baggage conveyer belt". - "Hand" was expressed by simply drawing "hand". One participant did not mention "hand" in the drawing and drew "red exclamation mark on the conveyer belt". - Six participants expressed "abrasion" as "hand bleeding red blood". Others did not mention it.

(No playing), R5 (Do not operate), R6 (Do not touch), and R7 (Hill water not suitable for drinking).

For referent R1 (Caution! Moving machine can crush hand), R6 (Do not touch) and R7 (Hill water not suitable for drinking), the action words were portrayed graphically. The graphical representations of the actions were concrete images of the tools used to realize the actions. For example, a cup, a glass or a lip for “drinking” in referent R7, hand or finger for “touch” in referent R6. The action “crush” in referent R1 was expressed by showing the results of the action like “the hand bleeding red blood” or by showing the situation that such kind of “crush” would happen e.g. placing the hand under a pressing machine.

For referents R4 (No playing) and R5 (Do not operate), the actions were not portrayed graphically. The participants chose graphical representations that were similar to the object of the functions e.g. what would be played and something that would be operated for the referents.

However, some participants did not address and ignore the action word in a referent. This might be due to the fact that actions which manipulate objects in specific ways are not easily represented graphically [14].

### C. Prohibition and Signal Words

Within the commonly used safety sign system, surround shapes are used to convey conventional meanings. Circular with diagonal bar, circular, triangular, square, and rectangular surround shapes mean prohibition, mandatory action, warning, safe condition/fire equipment, and supplementary information, respectively [15]. Most of the construction workers here used surround shapes to express the messages of prohibition and warning. Both circular with diagonal bar and triangular bounded shape were used to express the prohibition messages including “no”, “not”, and “do not” in R4 (No playing), R5 (Do not operate), R6 (Do not touch), and R7 (Hill water not suitable for drinking), and R8 (No thoroughfare). However, according to the current standards and guidelines in safety sign system, circular with diagonal bar refers to prohibition while the triangular bounded shape means warning.

Regarding the signal words, the construction workers used triangular, square, circular, and circular with diagonal bar surround shapes to connote the message of “caution” and “danger”. In safety sign system, triangular bounded shape signifies warning but square, circular, and circular with diagonal bar surround shapes connote mandatory action, safe condition and prohibition respectively.

Thus, we can see that for construction workers the choice of surround shape used was arbitrary which indicated that the workers were not familiar with and not understand the intended meanings of particular surround shapes in safety sign system. Surround shapes create conceptually related meanings and have a significant influence on reaching the criteria for sign effectiveness [16]. There is a need to enhance the understanding of safety sign elements for construction workers and the conceptual meaning of safety sign elements during safety training and promotion activities for the workers as earlier as possible.

## V. CONCLUSION

This research study examined the mental models of construction workers on safety sign representations in participatory sign redesign. The construction workers liked

to divide each safety sign referent into components and then portrayed the referent component by component. *Complete and incomplete referents* had a significant influence in participatory sign design. The extent of agreement among workers on common representation of the incomplete referents was not easily reached. The workers conceived and portrayed various possible graphical representations for each incomplete referent. *Action words* were expressed by illustrating the results of an action or the situation that such kind of action would happen. Occasionally the graphical representations of the actions were concrete images of the tools used to realize the actions. *Prohibition and signal words* were by and large expressed through surround shapes but the choice of surround shapes seemed to be arbitrary, indicating that the workers were not familiar with and not understand the intended meanings of particular surround shapes in safety sign system. The findings of this research study increased our understanding of the design rationale and justification for design decisions made and how the complete representation was built in participatory safety sign redesign among construction worker. These should help facilitate the process and practice of user-involved safety sign redesign in future and the optimization of participatory safety sign redesign for designing signs that can effectively convey intended meaning.

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