JSME Centenial Grand Congressby the Japan Society of Mechanical Engineers
International Symposium on OPtimization and Innovative Design (OPID97)
July 28 th to July 30 th, 1997 at Tokyo International Forum
Edited by H. Yamakawa, M. Yoshimura, S. Morishita and M. Arakawa
Paper #141

PERSONALIZATION OF CONCEPTUAL STRUCTURAL DESIGN ASSISTANT THROUGH GENETIC OPERATIONS

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In the conceptual design stage, design process are not always logical because of the lack of design criterion, procedure and knowledge clearly established. This process is dependent on the individual designer with specific design experience. The computerization of design process that consideration of the designer-dependent subjective aspects is important but a limited attention have been devoted to the computerization of such aspects. This article discusses the framework of the artificial design assistant for conceptual structural design, and its personalization to individual human designer. In this framework, the rule-based reasoning is used to generate and to evaluate the design candidates from multiple evaluation criteria to be considered by the human designer, and the genetic operations combined with the genetic case-base are used to suggest the candidate to the human designer with probabilistic uctuation. The progress of the design process is managed by the human designer through the interaction with the artificial design assistant. Based on the response of the human designer to the suggestion from the artificial design assistant, the preference of the artificial design assistant is adjusted to meet that of the human designer from the multiple evaluation criteria of the design in terms of the parameters for the genetic operations. Proposed idea is implemented and examined for the conceptual design of skeletal bridge structure including the constructive layout, the structural topology and geometry. The case studies demonstrate the effectiveness of the artificial design assistant with the personalization capability in this study.

1. INTRODUCTION

Design problem is recognized as a process to specify the framework of objective artifact, to define its attributes as the design variables, to find feasible attribute values as candidates, and to decide the best candidate as the design solution. In the case of conceptual design stage, these activities are not always logical because of the difficulties due to lack of design criterion, procedure and knowledge clearly established. The process is very qualitative and is dependent on the individual designer with specific design experience [(1)] . Computerization in the design activity has been challenging topics and has long history [(2)] . Much efforts has devoted to objective and logical aspects of design activities giving attractive results mainly in design stages following to the conceptual one. Although a little attention had been paid to the computerization of activities at conceptual design stage, its importance is obvious for the design activities including designer-dependent subjective aspects.

The authors have proposed an idea of artificial design assistant, a computerized system for conceptual structural design, that generates and suggests plausible design candidates to the human designer in accordance with the progress of designer's decision making in the design process. This article discusses the personalization of the artificial design assistant, that is a group of agents with different evaluation criteria for the design candidates. The personalization algorithm is proposed so that the presence of individual agents in the design assistant is adapted to the human designer's preference or subjective evaluation criterion through the adaptive optimization process of the genetic algorithm [(4)] . The concept is implemented and demonstrated with the conceptual design of skeletal bridge structure.

2. CONCEPT OF ARTIFICIAL DESIGN ASSISTANT

2.1 Idea of Artificial Design Assistant for Conceptual Structural Design

At the conceptual stage of structural design, the design space to be considered is very wide including constructive layout, structural topology, geometrical shape and so on. The design should be evaluated from various points of view not only of objective criteria based on mechanics or mathematics but also of subjective criteria such as of aesthetics [(5)] . In such a situation, the suitable key for the progress of design process is not the best based on rational optimization but the satisfaction or compromise based on heuristic trial-and-error[6]. In fact, there may be many feasible candidates for each design attribute and they generally are conflicting or competitive each other. Their preference as the candidate is dependent on the individual designer himself/herself, and his/her subjective decision making is the unique way to progress the design process[7]. That is, the expected computerization for design process is not an automatic progress of design activities, but an interactive stimulation to the human designer[8].

The artificial design assistant is the authors' answer to the computerization for such a design process. In the previous reports, the authors discussed the frameworks of the candidate generation based on the design rules considering the conflict and competition among candidates[9], based on the sensory evaluation of past design cases for aesthetic design[10], and based on the genetic case-base but partially free from the past cases[11]. These frameworks enable the artificial design assistant to suggest wide variety of design candidates available to the human designer. Although the artificial design assistant has its own preference among the generated candidates, it is not explicitly delivered to the human designer to make him/her free from the prejudice. The remaining problem is how to organize the preference of the artificial design assistant and the preference of the human designer.

2.2 Needs of Personalization

The preference of the human designer is directly connected to the design criterion and his/her decision making to progress the design process. It is related to the result of the overall evaluation of the design candidates from the various viewpoints, some of those are of logical, objective and quantitative and some of those are of heuristic, subjective and qualitative. It is, therefore, frequently difficult to state or declare the preference of the human designer in a specific and general manner by himself/herself. It, however, is important to adjust the preference of the artificial design assistant towards that of the human designer in order to suggest candidates to be expected, even in an implicit manner, by the individual human designer. This is referred to as the personalizetion of artificial design assistant in this article.

The response of the human designer to the design candidates suggested is the data to estimate the preference of the human designer. Thus, the personalization of the artificial design assistant is expected having the capability to adjust its preference in accordance with the response to the individual candidate suggested and to reflect to the following suggestions. It should also noted that an artificial design assistant is not the ultimate of the design assistant, because it does not able to stimulate the human designer with suggestion that are of completely hidden preference of the human designer. Figure 1 is the schematic diagram of the personalization of the artificial design assistant through the interaction with the human designer based on the iteration of candidates suggestion and corresponding response. This interaction is not only a chance for the personalization of the artificial design assistant but also a chance for the human designer to make his/her preference clear. It is also important that the suggestion of the artificial design assistant should be partially free from the preference of the human designer, even when the artificial design assistant has the same preference as that of the individual human designer.

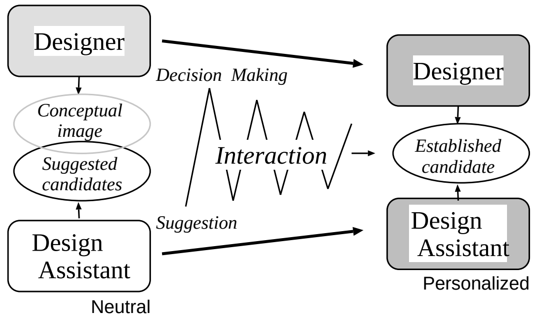


Fig. 1 Personalization at the conceptual design

3. PERSONALIZED ARTIFICIAL DESIGN ASSISTANT

3.1 Overview of Framework

Objective design artifact is represented by $\boldsymbol{s}$, a set of attribute values $s_i (i = 1, \cdots, I_s)$ of design variables, and a candidate is established when all of these values are decided. The process of decision making for the design attributes is divided into multiple steps connected to J_s ($J_s < I_s$) principle design attributes. Subproblems P_J ($J = 1, \cdots, J_s$) are defined corresponding to each of principle design attributes, and the set of attribute values is represented as $\boldsymbol{s} = \{s_1^{(r)}, s_2^{(r)}, \cdots, s_{i-1}^{(J-1)}, s_i^{(J)}, s_{i+1}^{(J)}, \cdots, s_{I_s}^{(J_s)}\}$, where superscript (r) denotes the attribute specified by the design requirement and (J) denotes the attribute to be decided at the subproblem P_J. At the subproblem P_J, the candidates generation by the artificial design assistant, the candidate suggestion to the human designer, and the decision of its acceptance or rejection by the human designer are performed based on the attribute values of design attributes with superscripts (r) and (j), $j = 1, \cdots, J-1$.

The artificial design assistant generates the candidates for a subproblem based on the rule-based reasoning, that permits the competitive candidates as much as possible. The evaluation of the generated candidates is carried out based on rule-based manner from multiple evaluation criteria both of quantitative and qualitative ones, and the

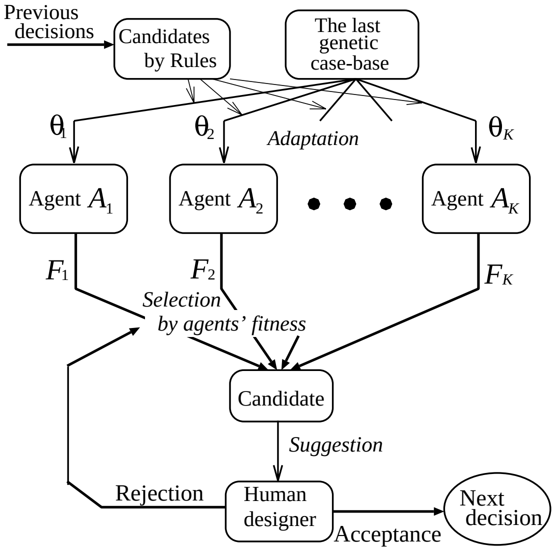


Fig. 2 Candidate suggestion by artificial design assistant with multiple agents

score v_k is marked for the criterion γ_k, $k = 1, \cdots, K$. The artificial design assistant has genetic case-bases, named agents A_k $(k = 1, \cdots, K)$, corresponding to each of evaluation criteria such as structural functionality, constructive easiness, and aethetics. The agents adapt their genetic case-base by referring to the similarity between the candidates generated by the rule-based reasoning and individual cases in their case-base population. The degree of adaptation is controlled by the self-convincing parameter θ_k defined for each agent A_k, corresponding to the selection pressure in the genetic operation. Each agent A_k has another parameter F_k, named fitness parameter, and the candidate suggested to the human designer is submitted from an agent selected based on this fitness parameter in the context of the roulette selection. The selected agent suggests a candidate based on its case-base by means of the genetic operation (Fig.2). These two parameters are used to characterize the preference of the artificial design assistant. The probabilistic features in the genetic operation is considered as the fluctuation of the suggestion of the artificial design assistant.

3.2 Genetic Representation of Structural Design Candidates and Evaluation

In order to cope with the diversity of design space including the constructive layout and the structural topology and geometry in a consistent manner, the artificial design assistant employs the genetic representation for the structural artifact, in which the real values of design attributes are recognized as the phenotype and is transformed from the genotype described by means of a chromosome(11). In this genotype representation, the chromosome coding is designed by the function-oriented manner. That is, the design attributes having the same or a similar function but apparently different phenotype are not distinguished in the chromosome coding.

The set $\boldsymbol{s}$ of attribute values of design variables are written by using the binary string $\boldsymbol{c} = \{c_1 \dots c_\ell \dots c_L\}$ of fixed length of L bits, where $c_\ell \in \{0, 1\}$. The difference in constructive layout and structural topology are represented as the allele site that works as their switching board, and their status gives the key to transform the genotype at the some allele sites having same function with different layout or topology to the phenotype. The genetic case-base of the agent A_k based on a specific evaluation criterion γ_k is used to evaluate the design candidate by means of the frequency of the candidate in individuals in the case-base population.

The similarity of two chromosomes $\boldsymbol{c}_i$ and $\boldsymbol{c}_j$ are defined as

$$\rho(\boldsymbol{c}_i,\, \boldsymbol{c}_j) = \sum_{m=1}^{M} {\lambda_m}^2 \,/\, L^2, \qquad (0 \le \rho \le 1) \tag{1}$$

by using the matching length λ_m, $m = 1, \cdots, M$. The exponent 2 of length λ_m takes the account of the length of matched string fragment in the chromosomes. When the chromosome $\boldsymbol{c}$ of a design candidate generated based on the rule-based reasoning for a certain subproblem, it inevitably has the allele sites of opened value in the chromosome. These sites are skipped without the discontinuity in the counting operation of string matching. The frequency of the chromosome $\boldsymbol{c}$ of a design candidate $\boldsymbol{s}$ in the chromosome population $\boldsymbol{C}(= \{\boldsymbol{c}_1, \cdots, \boldsymbol{c}_N\})$ is defined as

$$p(\boldsymbol{c},\, \boldsymbol{C}) = \sum_{i=1}^{N} \rho(\boldsymbol{c},\, \boldsymbol{c}_i) \,/\, N, \qquad (0 \le p \le 1) \tag{2}$$

by using the similarity $\rho(\boldsymbol{c}, \boldsymbol{c}_i)$. That is, $p(\boldsymbol{c}, \boldsymbol{C}_k)$ represents the evaluation of a design candidate $\boldsymbol{s}$ with chromosome $\boldsymbol{c}$ from the viewpoints of the evaluation criterion γ_k of agent A_k with case-base population $\boldsymbol{C}_k$.

3.3 Adaptation of Genetic Case-Base

For the subproblem P_J, the design candidates are generated by the rule-based reasoning based on the decided design attributes in the subproblems up to P_{J-1} and are identified by the suffix z as $\boldsymbol{s}^{(J)}_{(z)}$ $(z = 1, \cdots, Z)$. Each of them are marked with the score $v_{k(z)}$ through the evaluation from individual criterion γ_k by corresponding agent A_k. At the beginning of the first subproblem P_1, the agent A_k has the chromosome population $\boldsymbol{C}^{(1)[0]}_k$ as the initial generation of chromosome population of the original genetic case-base. The agent A_k carries out the genetic operation so as to reflect its criterion γ_k in the chromosome population of generation $[t]$ for the subproblem P_J, by using the fitness g_n of the chromosome $\boldsymbol{c}^{[t]}_{nk}$ $(\in \boldsymbol{C}^{(J)[t]}_k)$defined by

$$g_n(\boldsymbol{c}_{nk}^{[t]}) = \rho(\boldsymbol{c}_{nk}^{[t]},\, \boldsymbol{c}_{(z^*)})\, v_{k(z^*)}$$
$$z^* = \arg\max_z\ \rho(\boldsymbol{c}_{nk}^{[t]},\, \boldsymbol{c}_{(z)}) \tag{3}$$

where $\boldsymbol{c}_{(z)}$ denotes the genotype of the design candidate $\boldsymbol{s}_{(z)}$, and $\boldsymbol{s}_{(z*)}$ is the candidate most similar to the phenotype of $\boldsymbol{c}_{nk}^{[t]}$ among those candidates for subproblem P_J under consideration.

The simple genetic operations of the one-point crossover, and the mutation of bit inversion are used for the above operations. The chromosomes survived in the next generation of $[t+1]$ are determined by the standard roulette selection with the relative ratio $g_n/(g_1+\cdots+g_N)$ as the selection probabilities. The operation is terminated at the generation $[T]$, when the presence of the chromosomes having the best fitness becomes larger than the specified threshold parameter of selection pressure θ_k. The chromosome population $\boldsymbol{C}_k^{(J)[T]}$ is, then, the adapted case-base population $\boldsymbol{C}_k^{(J)}$ of the agent A_k. In this population, the chromosomes having higher evaluation from the evaluation criterion γ_k is the majority, and the threshold θ_k works as the self-convincing parameter of the agent A_k. That is, the evaluation of the chromosomes in the population is higher in average from the viewpoint of γ_k, when the self-convincing parameter θ_k is larger for the agent A_k.

3.4 Personalization of Artificial Design Assistant

As is mentioned in the section 3.1, each agent A_k of the artificial design assistant has the fitness parameter F_k. An agent that is expected to suggest a design candidate of the current subproblem P_J to the human designer is determined by the roulette selection with the selection probability $F_k/(F_1+\cdots+F_K)$ for the agent A_k. The selected agent A_{k^*} picks up a chromosome $\boldsymbol{c}_{k^*}^{(J)}$ randomly from the chromosome population of the adapted case-base $\boldsymbol{C}_{k^*}^{(J)}$, and its phenotype $\boldsymbol{s}_{k^*}^{(J)}$ is suggested to the human designer. The overall chance for the chromosome $\boldsymbol{c}_{k^*}^{(J)}$ to be suggested is the resultant of the fitness parameter F_k and the self-convincing parameter θ_k.

The human designer is able to accept or reject the suggested candidate from the artificial design assistant. When the suggestion is rejected, the artificial design assistant retries to select an agent that suggest a candidate again. At this moment, the artificial design assistant has the chance to adjust its preference to meet the preference of the human designer. In accordance with the rejection of the suggested candidate from the agent A_{k^*}, this agent is discouraged and its fitness parameter is reduced to $r_d F_{k^*}$ with the discouraging factor r_d $(0 < r_d < 1)$.

When the suggestion is accepted, the design process moves to the subsequent subproblem P_{J+1}. In order to make the adapted genetic case-base for the subproblem P_{J+1}, the initial generation of the chromosome population $\boldsymbol{C}_k^{(J+1)[0]}$ is refreshed to a new one, that consists of $N \times F_\kappa/(F_1+\cdots+F_K)$ chromosomes randomly selected from the adapted case-base $\boldsymbol{C}_\kappa^{(J)}$ $(\kappa = 1, \cdots, K)$ of the previous subproblem P_J. This new set of chromosomes migrated from chromosome populations of different evaluation criteria is expected to have a chance including the chromosomes that fit to the multiple evaluation criteria. The new chromosome population as the initial generation for the subproblem P_{J+1} is sent to the selection process described in the section 3.3, and the adapted genetic case-bases $\boldsymbol{C}_k^{(J+1)}$ are established. At this moment, the agent A_{k^*} whose suggestion at the subproblem P_J is accepted by the human designer is encouraged as the counterpart of the reduction of fitness parameters in the above paragraph. That is, the self-convincing parameter θ_{k^*} of the agent A_{k^*} is increased to $w_a\theta_{k^*}$ with the encouraging factor w_a (> 1). This increase of the selection pressure permits the agent A_{k^*} to have more convinced genetic case-base from the viewpoint of its own evaluation criterion γ_{k*}.

4. ILLUSTRATIVE EXAMPLES

4.1 Basic Behavior

Let consider a skeletal structural design of a steel road bridge under the conditions of length of 500m, width of 20m, bridge span of over 300m as shown in Fig.3. Three evaluation criteria of structural functionality γ_1, structural aesthetics γ_2, and cost-effectiveness γ_3 are considered for the design evaluation. The word, elegance, is assumed as the design motif and is used to evaluate from the aesthetic point of view. The evaluation rules for γ_1 and γ_3 are organized based on the bridge design manuals and guidelines, and that for γ_2 is established from the sensory evaluation of the past design cases[10]. The population size of genetic case-base for agents of the artificial design assistant is assumed to be $N = 5000$. The parameters for simple genetic operation are of 0.8 for the chance of one-point crossover and of 0.05 for the mutation. The initial values of fitness parameters are assumed to be $F_k = 1/3$ and those of self-convincing parameters be $\theta_k = 0.1$. The discouraging factor is $r_d = 0.8$, and the encouraging factor is $w_a = 1.2$.

Figure 4 shows (1) the design candidates generated by rule-based reasoning and (2) the chromosome distribution

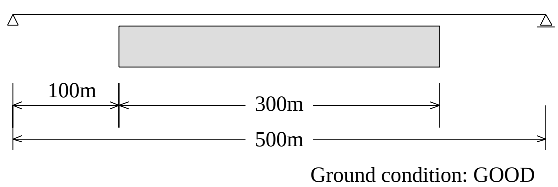
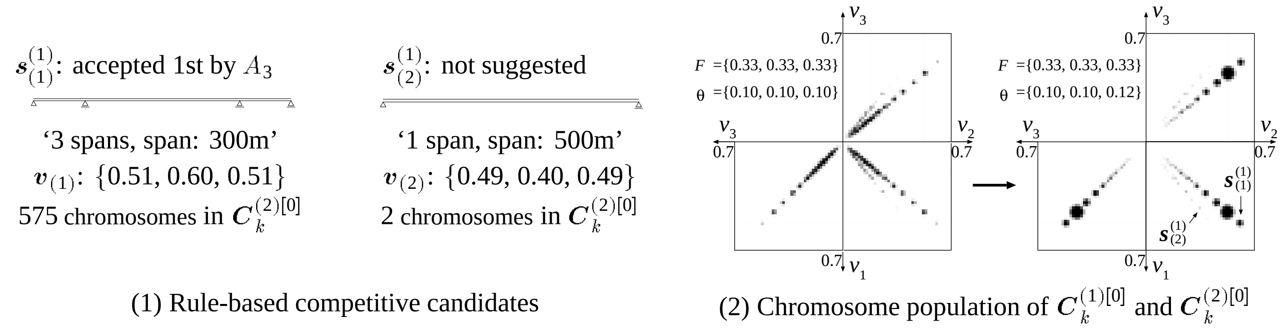


Fig. 3 Example case of specified design requirement



(1) Rule-based competitive candidates

(2) Chromosome population of $C_k^{(1)[0]}$ and $C_k^{(2)[0]}$

(a) Subproblem P_1 of span assignment

(1) Rule-based competitive candidates

(2) Chromosome population of $C_k^{(7)[0]}$ and $C_k^{(8)[0]}$

(b) Subproblem P_7 of hanger-type determination

Fig. 4 Design candidates and personalization of artificial design assistant (assistantA)

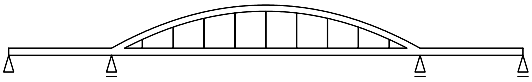


Fig. 5 3-spanned Lohse arched bridge established by designer A and assistant A

of the initial generation of genetic case-base for (a) the first subproblem P_1 of the span assignment and (b) the last subproblem P_7 of the hanger-type determination for arched bridge in this case. For the subproblem P_1, the candidate $s^{(1)}_{(1)}$ of 3 spans suggested by the agent A_3 is accepted at the first suggestion from the artificial design assistant. As the result of this decision by the human designer, the cases corresponding to the accepted candidate $s^{(1)}_{(1)}$ is increased in the chromosome population $C_k^{(2)[0]}$ for the following subproblem P_2 for determination of bridge-type as shown in (a)(2). For the subproblem P_7, the human designer rejected Nielsen-type hanger at the first and second suggestions of the artificial design assistant, and accepted the vertical hanger suggested by the agent A_1 at the third suggestion. That is, this human designer reached to the Lohse-type arched bridge shown in Fig.5, and the fitness parameters and self-convincing parameters are adjusted to $F = \{0.25, 0.49, 0.25\}$ and $\theta = \{0.14, 0.21, 0.12\}$. These values of parameters mean the human designer mainly accept the suggestion from the agent A_2 that evaluate the candidate from the viewpoint of structural aesthetics.

Table 1 shows the frequency of the rule-based design

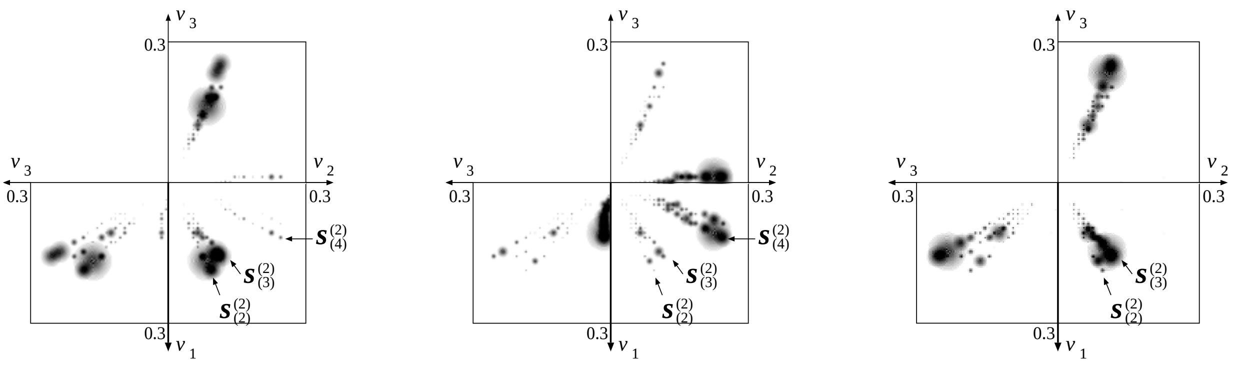
Table 1 Presence of rule-based candidates in the adapted genetic case-base population by the agents at P_2

Self-convincing	θ_1: 0.10	θ_2: 0.10	θ_3: 0.12
Candidates: $(v_{k(z)})$	by A_1 in $C_1^{(2)}$	by A_2 in $C_2^{(2)}$	by A_3 in $C_3^{(2)}$
$s^{(2)}_{(1)}$: (0.08, 0.25, 0.02)	2	53	0
$s^{(2)}_{(2)}$: (0.19, 0.09, 0.18)	515	4	40
$s^{(2)}_{(3)}$: (0.16, 0.12, 0.26)	632	47	704
$s^{(2)}_{(4)}$: (0.11, 0.25, 0.02)	29	513	0
$s^{(2)}_{(5)}$: (0.12, 0.08, 0.14)	108	17	118
$s^{(2)}_{(6)}$: (0.19, 0.09, 0.18)	0	0	0
$s^{(2)}_{(7)}$: (0.16, 0.12, 0.21)	58	8	41

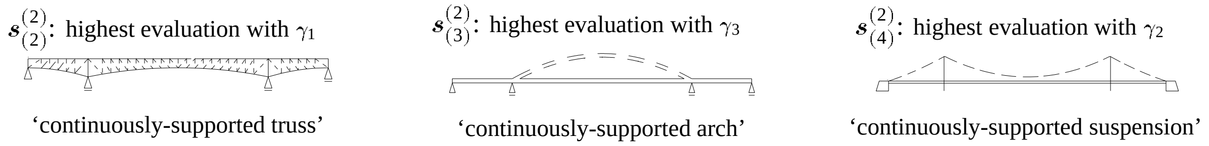
candidates in the adapted case-base population $C_k^{(2)}$. Although the chromosome population at the first generation $C_k^{(2)[0]}$ are the same for all agents, the adapted case-bases of agents A_1, A_2 and A_3 show characteristic chromosome distributions as shown in Fig.6. As the result, the frequencies of the candidates in the adapted case-base is clearly different as is found in Table 1, and the suggestions from these agents are obviously different each other.

4.2 Personalized Assistance

If the artificial design assistant has the chance to cooperate with the same designer with the same design problem, its suggestion is expected to be close to the preference of the human designer to some extent. Figure 7(a) shows the chromosome distribution of the adapted case-



(a) Chromosome population of $C_1^{(2)}$ of agent A_1 (b) Chromosome population of $C_2^{(2)}$ of agent A_2 (c) Chromosome population of $C_3^{(2)}$ of agent A_3



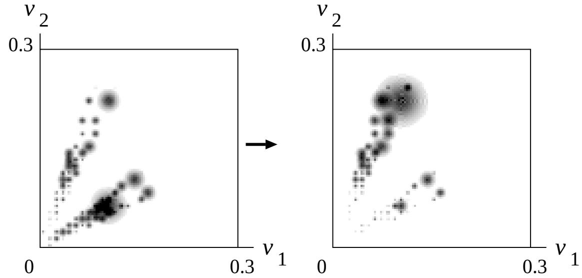
(d) Typical candidates by rule-based reasoning

Fig. 6 Adapted case-base population at subproblem P_2 (assistant A)

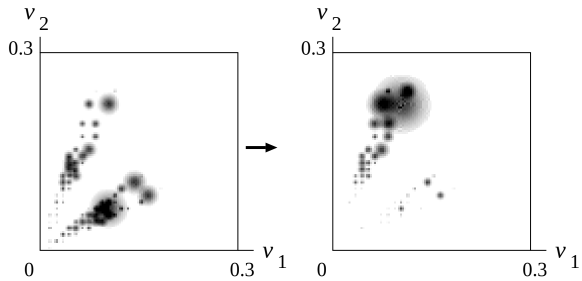
base $C_2^{(2)}$ of agent A_2 in v_1 and v_2 space during the first session described in the section 4.1, and (b) shows that during the second session starting from the fitness and self-convincing parameters obtained as the result of the first session. Due to the difference of the self-convincing parameter $\theta_2 = 0.10$ and 0.21, the preference of human designer towards the evaluation criterion γ_2 is strongly reflected to the distribution pattern in the case of the second session. This is an evidence that the artificial design assistant has the capability to adjust its preference toward that of the human designer through the assisting sessions.

Let consider another human designer, say designer B, of different preference from the previous human designer, say designer A. When the previous problem is treated by the human designer B and the 3-spanned Pratt truss bridge in Fig.8 is the resultant design, the fitness and self-convincing parameters are adjusted to $F = \{0.41, 0.33, 0.26\}$ and $\theta = \{0.21, 0.12, 0.10\}$ starting from the same initial values in the case of designer A. This artificial design assistant personalized by the designer B is distinguished as the assistant B from the artificial design assistant personalized by the designer A, say the assistant A, of $F = \{0.25, 0.49, 0.25\}$ and $\theta = \{0.14, 0.21, 0.12\}$. The bridge-type is the main difference of the designs of Figs.5 and 8 by designer A and B.

Figure 9 shows the chromosome distribution of the population of $C_k^{(2)[0]}$ and $C_k^{(3)[0]}$ by the assistants A and B during the second session. As is listed in Table 2, the design candidates $s_{(4)}^{(2)}$ and $s_{(3)}^{(2)}$ makes the majority in the chromosome population $C_k^{(3)[0]}$ in the case of the assistant A, and the design candidates $s_{(2)}^{(2)}$ and $s_{(3)}^{(2)}$ makes the majority in the case of the assistant B, as the result of decision making on the bridge-type. The difference of the presence of $s_{(4)}^{(2)}$ and $s_{(2)}^{(2)}$ are recognized as the result of the



(a) The first session (adaptation from $C_2^{(2)[0]}$ to $C_2^{(2)}$ with $\theta_2 = 0.10$)



(b) The second session (adaptation from $C_2^{(2)[0]}$ to $C_2^{(2)}$ with $\theta_2 = 0.21$)

Fig. 7 Adapted case-base population for subproblem P_2 by agent A_2 (assistant A)

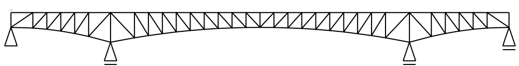
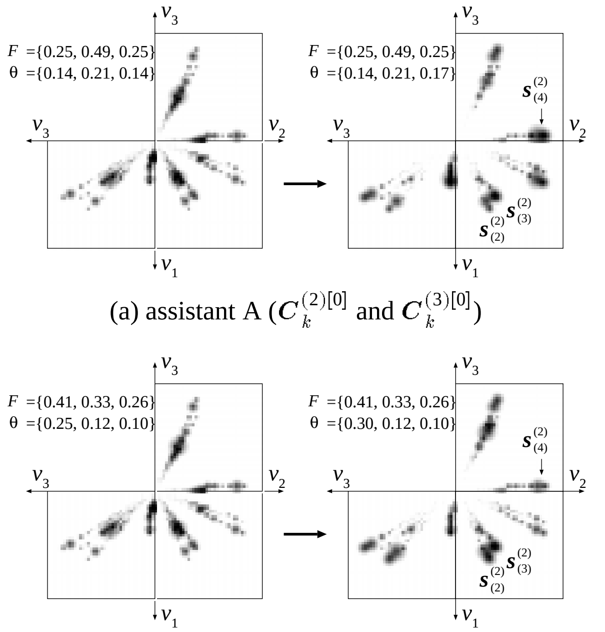


Fig. 8 3-spanned Pratt truss bridge established by designer B and assistant B



(a) assistant A ($\boldsymbol{C}_k^{(2)[0]}$ and $\boldsymbol{C}_k^{(3)[0]}$)

(b) assistant B ($\boldsymbol{C}_k^{(2)[0]}$ and $\boldsymbol{C}_k^{(3)[0]}$)

Fig. 9 Chromosome distribution in $C_k^{(3)[0]}$ as the result of sub-problem P_2

Table 2 Presence of the design candidates in the chromosome population $C_k^{(3)[0]}$ at the end of P_2 on the second session

Candidates	$\boldsymbol{s}_{(1)}^{(2)}$	$\boldsymbol{s}_{(2)}^{(2)}$	$\boldsymbol{s}_{(3)}^{(2)}$	$\boldsymbol{s}_{(4)}^{(2)}$	$\boldsymbol{s}_{(5)}^{(2)}$	$\boldsymbol{s}_{(6)}^{(2)}$	$\boldsymbol{s}_{(7)}^{(2)}$
assistant A	6%	18%	29%	35%	6%	0.8%	5%
assistant B	3%	40%	33%	14%	6%	1%	2%

difference of the fitness and self-convincing parameters of the evaluation criterion of γ_2 and γ_1 for the assistants A and B. These are the result of the personalization of the artificial design assistant to the different human designers. It is noted here that both of assistant A and B of different personalization are able to suggest all of possible design candidates by means of the probabilities shown in Table 2. This means the suggestions of personalized assistants are not restricted to the narrow preference.

5. CONCLUSIONS

A concept of artificial design assistant is discussed for the conceptual structural design, at which the subjective and qualitative decision making of the human designer plays the essential role. In the artificial design assistant, the rule-based reasoning is used to generate and to evaluate the design candidates to be considered by the human designer, and the genetic operations combined with the genetic case-base are used to suggest the candidate to the human designer with probabilistic fluctuation. The progress of the design process is managed by the human designer through the interaction with the artificial design assistant. Based on the response of the human designer to the suggestion from the artificial design assistant, the preference of the artificial design assistant is adjusted to meet the preference of the human designer from the multiple evaluation criteria of the design in terms of the parameters for the genetic operations of the artificial design assistant. This gives us the framework of the personalization of the artificial design assistant to the individual of human designers with their own preferences. Proposed idea is implemented and examined for the skeletal design of bridge structure including the constructive layout and the structural topology and geometry. The case studies demonstrate the effectiveness of the artificial design assistant with the personalization capability in this study.

REFERENCES

(1) Maher, M.L., "Expert System for Structural Design," *J. Comp. in Civil Eng.*, **1**-4, (1987), pp.270-283.

(2) Cross, N., "Science and Design Methodology: A Review," *Res. in Eng. Design*, **5**-2, (1993), pp.63-69.

(3) e.g., Thurston, D.L., "A Formal Method for Subjective Design Evaluation with Multiple Attributes," ibid, **3**-3, (1991), pp.105-122.

(4) Goldberg, D.E., "Genetic Algorithms in Search, Optimization and Machine Learning," Addison-Wesley (1989).

(5) Reich, Y., "A Model of Aesthetic Judgment in Design," *Artificical Intelligence in Engineering*, **8**-2, (1993), pp.141-153.

(6) Akagi, S., Engineering Design (Vol.1) —New Methodology for Computer Application to Design—, (1991), p.9 (in Japanese).

(7) Akagi, S., ibid, p.60 (in Japanese).

(8) Taura, T., "Engineering Knowledge and Research into Artifacts," *J. of JSPE*, **61**-4, (1995), pp.477-480 (in Japanese).

(9) Tanaka, M., Seguchi, Y. and Yamaguchi, T., "An Expertized Assistant for Conceptual Design of Bridge Structure Based on Design Knowledge Permitting Fluctuation," *Proc.of 3rd EPMESC International Conference, Macau*, (1990), pp.235-245.

(10) Tanaka, M. and Hira, T., "Sensory Evaluation of Past Design Cases and Design Candidates for Conceptual Structural Design," *JSME Int. J.*, **39**-3, Ser.C, (1996), pp.645-651.

(11) Tanaka, M. and Hira, T., "Genetic Case-Base for Conceptual Structural Design," *Proc. of 1994 Japan-U.S.A Symposium on Flexible Automation, Kobe* (ISCIE&ASME), Vol. III, (1994), pp.1337-1340.