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An integrated cognitive computing approach for systematic conceptual design

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Summary of the existing papers on systematic conceptual design

1. Matrix-based conceptual design method
   employs matrix to represent PS knowledge and uses matrix operations to synthesize PSs

2. Bond graph-based conceptual design method
   employs three types of analogies (i.e. signal analogies, component analogies, and connection analogies) to generate PSs of engineering system for a desired function

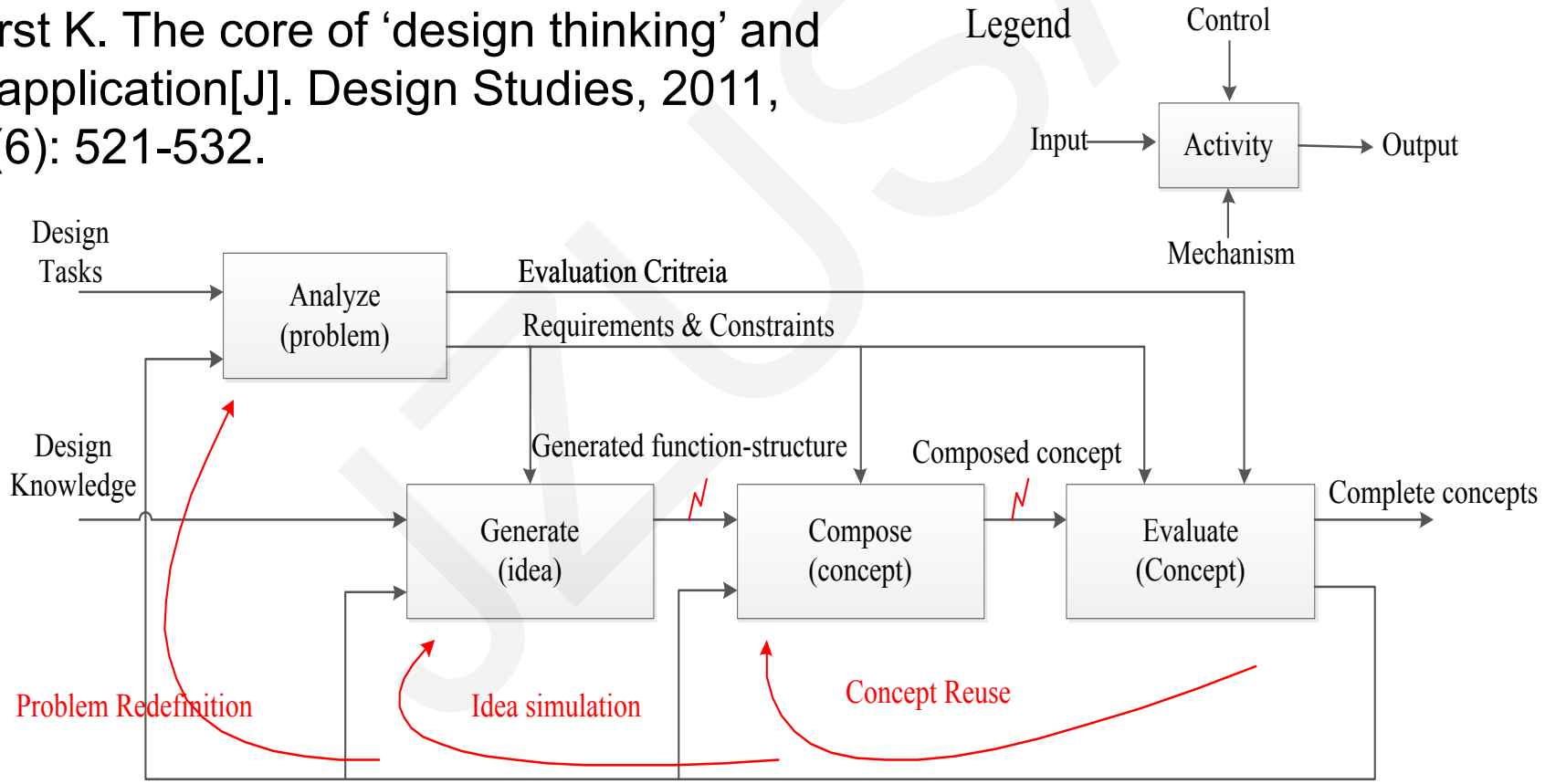
3. Grammar-based conceptual design method
   captures design knowledge by defining a vocabulary and rule set, often involved syntax, semantics, and pragmatics, which operates over design elements to produce concept solutions

4. Function-based conceptual design method
   generating conceptual solutions through combining function of PSs

Cognitive computing model of conceptual design

Based on Dorst's research, this paper proposes a cognitive computational model of conceptual design that is composed of four major cognitive activities, namely, analysis, generation, composition, and evaluation.

Dorst K. The core of 'design thinking' and its application[J]. Design Studies, 2011, 32(6): 521-532.



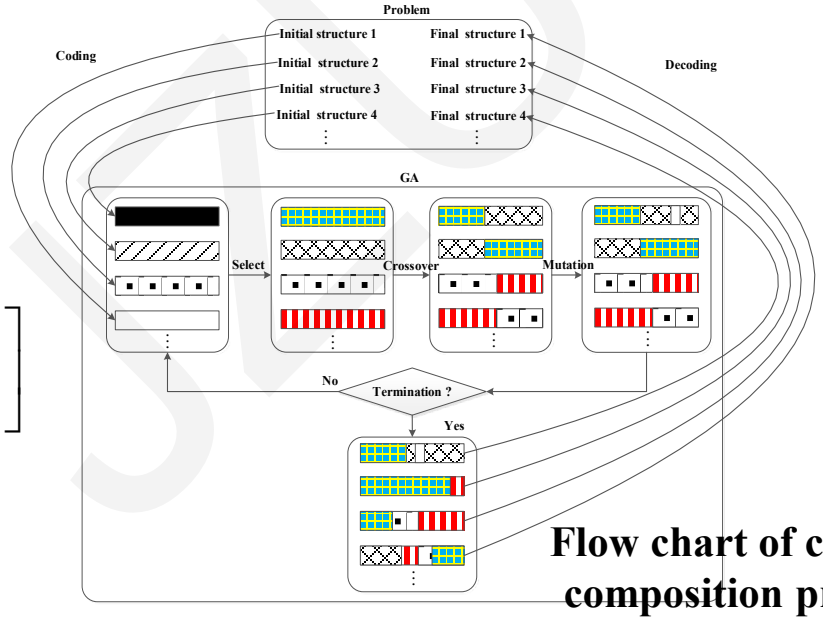
Computational conceptual design stimulation

- Hopfield neural network simulates human cognitive behavior, which can use previous experience and preexisting knowledge to solve new problems.
- Morphology matrix is used to search for a feasible solution to the corresponding problem by trying out all possible combinations and GA is applied to stimulate concept combination.
- A fuzzy TOPSIS approach integrating triangular fuzzy number and linguistic variables is proposed to generate the overall score for each candidate.

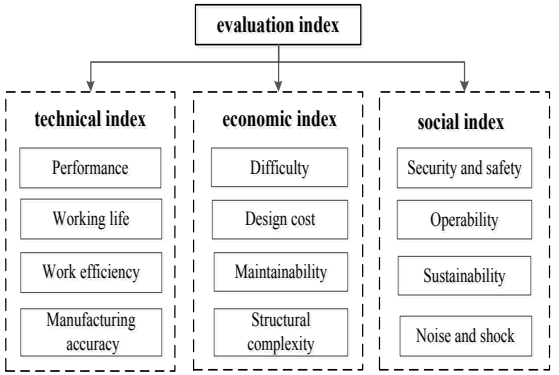
$$w = \frac{1}{n}\sum_{k=1}^{m}(u_k u_k{}^T - I)$$

$$\begin{cases} v_i^{(0)} = u_{0i} \\ v_i^{(k+1)} = \operatorname{sgn}\left[\sum_{j=1}^{n} w_{ij} v_j^{(k)} - \theta_i\right] \end{cases}$$

Concept generation

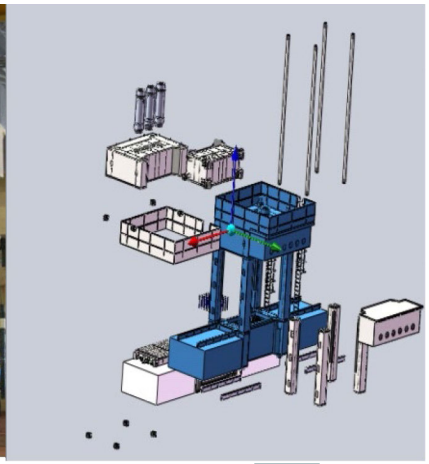


Flow chart of concept composition process

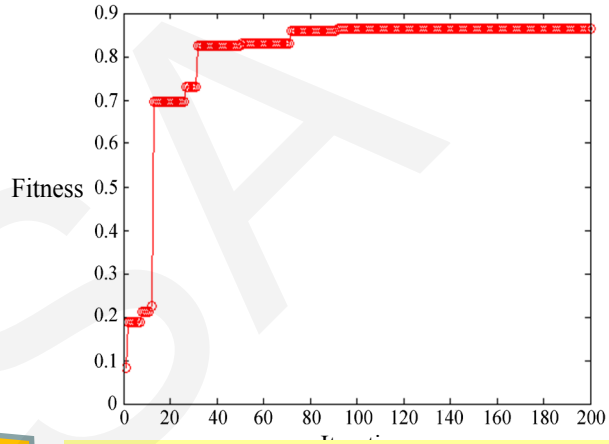


Evaluation index

Case study



hydraulic press



GA-based concept composition process

Function unit	Solution set
1 motion	plunger-type cylinder ( ), piston cylinder ( ), differential plunger hydraulic cylinder ( )
2 guide	45C plunger ( ), 50C plunger ( ), cast iron plunger ( )
3 guide	alloy guide sleeve ( ), nylon guide sleeve ( )
4 seal	V-type sealing ( ),U-type sealing ( ),Y-type sealing ( ), O-type sealing ( )
5.bearing	Modular framework ( ),integral type frame ( ),concrete frame ( )

Morphology matrix of principle solutions of hydraulic press

No.	Design result	fitness
1	$S_{13}+S_{22}+S_{31}+S_{44}+S_{51}$	0.834
2	$S_{11}+S_{22}+S_{31}+S_{41}+S_{53}$	0.789
3	$S_{13}+S_{23}+S_{31}+S_{43}+S_{52}$	0.756
4	$S_{12}+S_{21}+S_{32}+S_{41}+S_{52}$	0.688
5	$S_{13}+S_{22}+S_{32}+S_{42}+S_{52}$	0.558

Computation result

Conclusions

- Current CACD tools provide major support to embodiment design and detailed design, but they fail to provide sufficient help to conceptualization. Furthermore, even if designers have sufficient knowledge, it may be difficult to acquire satisfactory solutions efficiently if not guided by computers
- This paper proposed an integrated cognitive computing approach based on the integration of engineering design and cognitive psychology, which is composed of concept associative memory, concept generation, and the decision-making process. Hopfield neural network, GA, and TOPSIS were applied to obtain the best solution.
- Further research will focus on big data-based conceptualizing approaches encompassing design data acquisition, representation, and application.