Title:
A Framework for Concept Formation in CAD Systems: a Case Study of Japanese Rock Garden Design

Authors:
Yuval Kahlon, kahlon.y.aa@m.titech.ac.jp, Tokyo Institute of Technology
Haruyuki Fujii, fujii.h.aa@m.titech.ac.jp, Tokyo Institute of Technology

Keywords:
Concept Formation, Spatial Design, Logical-Inference Systems, Japanese Rock Garden

DOI: 10.14733/cadconfP.2019.34-38

Introduction:
Computer-Aided Design (CAD) systems enable designers to create digital representations of their designs by storing, manipulating and visualizing information regarding the designed artifact's configuration [1]. Utilizing object-oriented approaches, CAD systems continuously strive to minimize the gap between the designer's conceptual understanding of the artifact being designed, and its digital representation [4]. As a result, advanced CAD systems (for example: Building Information Modeling systems in the field of architecture) are highly informed with respect to the representation's denotative meaning in the designer's conceptual world.

Contrary to this, most systems are less informed regarding the representation's connotative meaning in the designer's mind. This paper proposes an implementable framework for concept formation in CAD environments, to enable designers inform the system regarding possible connotative meanings of spatial configurations, in a given context. This is conducted by representing and storing spatial configurations as high-level descriptions, enabling designers to encapsulate desirable design typologies in concise verbal expressions. The proposed framework was implemented and tested in the context of Japanese rock garden design (JRGD), by storing popular rock configuration typologies as short verbal descriptions, and retrieving them from memory.

Main Idea:
Background
Tying desired sets of spatial relations under a single verbal description is an old-time design practice, evident as early as in the classical Greek orders of architecture (Fig. 1), where certain proportions and parts are explicitly named as a single entity (i.e. Doric etc.). These names form a conceptual framework for the design of artifacts, by serving as high-level abstractions of multiple spatial relations. Such abstractions denote a range of desired design solutions, while connoting with additional possible meanings that may be attributed to the artifact by the designer. In the above example, the description "Doric" denotes a certain set of column parts and their relative proportions, while connoting the design with the concepts of masculinity and dignity often attributed to such columns [5].

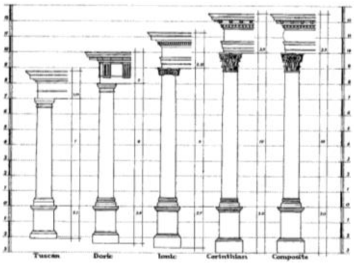

Fig. 1: The Greek orders; an early form of formalizing spatial relations (source: Chitham R., The Classical Orders of Architecture).

Facilitating the above practice in current CAD systems will not only enable designers to construct digital conceptual frameworks, but will inform the system with respect to high-level semantic attributes which the designer associates with a given spatial configuration. How may we formalize this practice, to enable its support by current CAD systems? Towards this end, we have examined it in the context of JRGD, which has served as suitable grounds for an initial investigation of this practice, owing to two main considerations 1) its frugal nature consisting on a relatively small number of well-defined elements 2) its flexibility with respect to concept formation (as compared with the rigid nature of concepts in Greek architecture, for example, which allows minimal freedom for the designer, when applying the concepts in their designs).

As an abstract form of art, JRGD makes extensive use of conceptual descriptions denoting a specific design typology, to the extent of offering a composition catalog for designers, as a reference for selecting and positioning rocks in the garden space [6]. These descriptions are not arbitrary names, but rather connote with high-level meanings that are attributed to the design. In (Fig. 2, c) we present an example of a configuration attributed with the concept "Dry Waterfall". This attribution implies on certain spatial relations (for example, verticality, downward flowing texture etc.), while tying the configuration with connotative meanings external to the designed artifact (the concept of water, natural scenery etc.). By analyzing the relation between the spatial configuration and its description in existing compositions, we may progress towards formalizing this practice of concept formation, to implement it in CAD systems.

Fig. 2: Examples for common typologies serving as high level conceptual abstractions in JRG design, in varying levels of complexity: (a) "Buddhist Triad" (Tofujuki temple, Kyoto) (b) "Crane Island" (Tofukuji temple, Kyoto) (c) "Dry Waterfall" (Senshūkaku garden, Tokushima; source: japanesegardening.org).

Aim
The aim of this research is to enable users to inform CAD systems regarding possible connotative meanings of spatial configurations, by allowing designers to externalize conceptual structures of signification and representation as formal descriptions.

Method and Scope
In order to establish the proposed framework for tying concepts with spatial configurations we have 1) studied this practice in the context of JRGD design, by conducting a literature review of the traditional manuals [6][7] and documenting rock configurations in classical JRG 2) devised a standardized syntax to express common concepts as sets of lower-level entities 3) digitized a collection of small rocks using a desktop 3D scanner and stored them as mesh geometries, as a preparatory step for the implementation 4) implemented the framework by integrating the 3D CAD environment Rhinoceros with the logical inference system SWI-Prolog 5) constructed a set of formal concepts and attempted to automatically match them with spatial configurations using our system.

This paper focuses solely on the spatial configuration aspect of rock composition in JRGD, while excluding other JRGD elements from consideration (such as the moss, gravel etc.); while the other elements greatly contribute to the design and affect its interpretation by users, the traditional manuals of JRGD teach us that the rocks serve as the foundation for the design activity, and are strongly viewed as the backbone of the design [8]. Evidently, the classical manual for general Japanese garden design opens with the words "The art of setting stones", reflecting their centrality in this art form [7]. Accordingly, we have chosen to begin developing the framework by focusing on the rocks, while keeping in mind the need for extending it to include additional elements in the future. Similarly, the aesthetic dimension of the composition is beyond the scope of this paper, considering that it may be integrated later as an additional layer of filtering and searching the solution space resulting from our framework, according to the visual desirability of potential spatial configurations.

Significance and Contribution
The main contribution of this research is the proposed computational framework, which enables users to assign meaning to the digital representations of their designs, by adding a layer of high-level semantic descriptions. This framework expands the notion of meaning in CAD systems, enabling designers to embed conceptual information into their digital models. Among the potential implications are 1) enabling to store and share conceptual frameworks and desirable design typologies among designers 2) contributing to development of co-creative design systems, capable of understanding high-level conceptual abstractions 3) supporting automatic semantic enrichment processes in CAD systems.

Proposed Framework
The proposed framework is used to construct high-level concepts by combining multiple lower-level entities (Fig. 3). This framework is inspired by Gero's FBS framework [3] and Gardenfors's Conceptual Spaces framework [2]. We define four main entities: behaviors, relations, meanings and concepts. Each entity is assigned with a formal syntactic representation, following the syntax of Prolog (a logical programming language). The formal syntax enables to harness logical inference systems for matching spatial configurations with high-level descriptions. A valid matching of a concept with a spatial configuration is inferred by logically deriving the existence of the associated lower-level entities in the system.

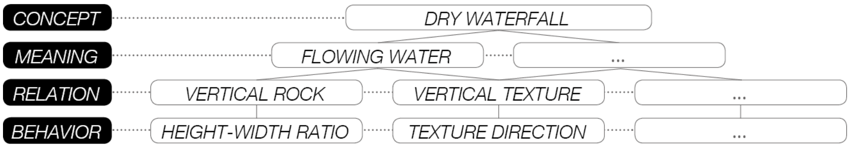

Fig. 3: A partial formalization of the concept "Dry Waterfall" from (Fig. 2, c) using our framework.

Implementation & System Behavior
In order to implement the framework, we have created a live connection between a 3D environment (Rhinoceros 3d) and an inference system (SWI-Prolog). This implementation enables users to 1) create concepts by selecting and combing relations from a pre-defined relation pool, via a simple graphical user-interface (GUI) referred to as "concept editor" (Fig. 4) 2) create spatial configurations from a digital rock collection 3) automatically match the configuration with a high-level concept, according to the currently defined concepts. The process of using the system consist of four main steps, as shown below in (Fig. 5).

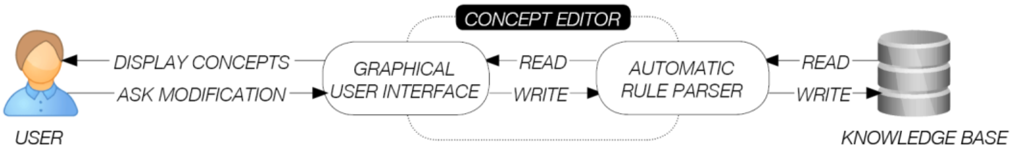

Fig. 4: Creating and managing a concepts knowledge base by utilizing an automatic parser.

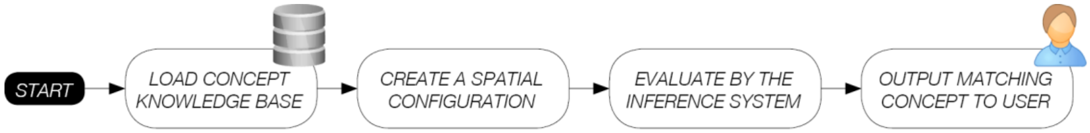

Fig. 5: Matching concepts with spatial configurations using the system.

Results and Discussion
The ability of the system to tie spatial relations with verbal descriptions was demonstrated by 1) defining a set of basic dual and triad spatial relations 2) utilizing the above relations to define a set of ten concepts 3) randomly generating spatial configurations consisting on three rocks 3) auto-evaluating these configurations using the inference system and recording the matching concepts given as output. Below are two examples for automatic matchings between configurations and concepts produced by the system, as well as a concise breakdown of each concept into lower-level entities (Fig. 6). The left composition (Fig. 6, a) was matched with the concept "a mountain range" via identifying consecutive overlapping between elements, as well as similarity in orientation; the right composition (Fig. 6, b) was matched with the concept "parent watching brothers", owing to the height similarity between the two small rocks, and their size relation to the larger one, as well as their proximity relations.

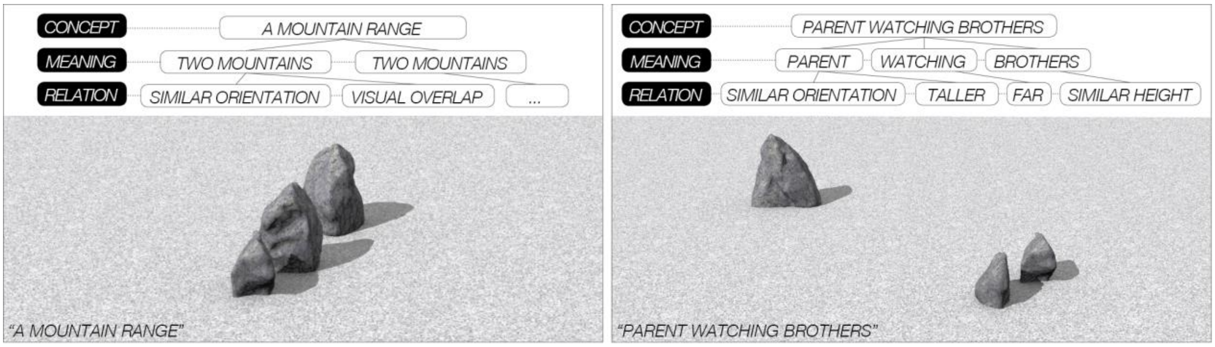

Fig. 6: Examples of automatic matchings between a defined concept and a spatial configuration: (a) "a mountain range" (b) "parent watching brothers".

An important aspect which calls for further research is the possibility of auto-formulation of concepts. Although manual formulation using a GUI is possible, it is a time-costly task which demands designers to reflect upon their conceptualizations, analyze them and then re-construct them using the proposed syntax. These burdens can be gradually removed from the process by further developing classification modules to automatically derive formal concepts from existing design representations, guided by an input from the designer.

Finally, with respect to the generalizability of the proposed framework - since the framework does not make any assumptions regarding the nature of the elements in discussion, it is generalizable, to a large extent, for a wide range of artistic or design domains consisting of spatial configurations (architecture, sculpture etc.), including those of a lower dimensionality (graphic design etc.). Yet, utilizing this framework in-practice in a different context would require a preliminary three-step process: 1) determining which elements are to be represented as basic entities 2) defining the behaviors of these entities which are domain-specific 3) defining the relations between these entities which are domain-specific, given these behaviors.

Conclusions:

The proposed framework enables a structured approach for creating high-level abstractions of spatial configurations, encapsulating them in concise verbal descriptions named concepts. These concepts can metaphorically be seen as words forming the vocabulary of the designer's internal world, or the building blocks of an artistic style. Thus, further developing the framework to express different relations between a set of concepts in a given context may serve in constructing the syntax and grammar which constitute distinct stylistic forms of expression. Moreover, although the concepts are formed here manually by the designer via interacting with our interface, the process can be greatly simplified by further research targeted at auto-generation of concepts. This can be done via supervised-learning-based processes, by matching concepts with their corresponding relations (while being guided by the designer) and phrasing them as formal entities in the system.

References:

[1] Fujii, H.; Aoki, Y.: Dual deep-structure to associate a shape with its linguistic description: a hypothetical framework and an experimental implementation, Journal of Asian Architecture and Building Engineering, 2(1), 2003, 115–121. https://doi.org/10.3130/jaabe.2.115

[2] Gärdenfors, P.: Conceptual Spaces, Massachusetts Institute of Technology press, USA, 2000. https://doi.org/10.7551/mitpress/2076.001.0001

[3] Gero, J.: Design Prototypes: A knowledge representation schema for design, AI Magazine, 11(4), 1990, 26-36.

[4] Kalay, Y. E.: Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design, Massachusetts Institute of Technology press, USA, 2004.

[5] Onians, J.: Bearers of Meaning. New Jersey: Princeton University Press, 1988.

[6] Slawson, D.: Secret Teachings in the Art of Japanese Gardens: Design Principles, Aesthetic Values, Kodansha International, Tokyo, 1991.

[7] Takei, J.; Keane, M. P.: Sakuteiki, Visions of the Japanese Garden: A Modern Translation of Japan's Gardening Classic, Tuttle Publishing, Vermont, 2001.

[8] Van Tonder, G. J.; Lyons M. J.: Visual perception in Japanese rock garden design, Axiomathes, 15(3), 2005, 353–371. https://doi.org/10.1007/s10516-004-5448-8