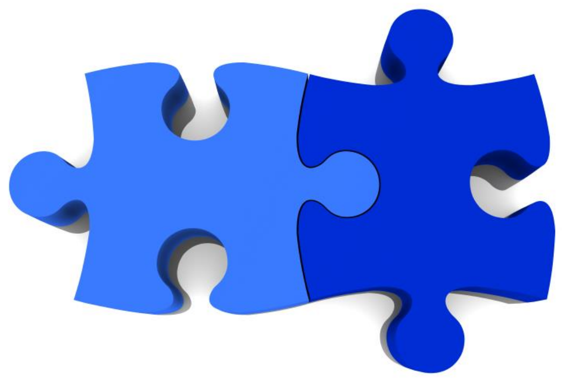


FINDING A CONCEPT

Fall 2019

SUBJECT

Smart Generation of Architectural Plan

Sanaz Ahmadzadeh Siyahrood

Idea Seminar

	Title of Paper	Year	Publisher	Description
1.	Note on "Synthesis and Optimization of Small Rectangular Floor Plans" of Mitchell, Steadman, and Liggett	1977	Environment and Planning B: Planning and Design 4 (1), 81-88	
2.	Computer aided dimensioning of architectural plans	1978	CAD78, IPC Press, Guilford, 482-493	A system for the computer aided dimensioning of architectural plans is described. It is based on the use of dynamic programming to optimize the room dimensions to minimize the construction cost while satisfying the various planning constraints. The designer works at an Interactive graphics terminal and uses a command language to control the system. The results are presented both graphically and numerically. The designer can examine all feasible solutions as well as the optimal solution. The results are then used as a database for a drafting program. With this system the problem of generating the geometry of a design has been solved.
3.	Computer-aided design by optimization in architecture	1980	Design Studies 1 (4), 227-230	
4.	The theoretical framework	1984	The Taxation of Income from Capital: A Comparative Study of the United …	
5.	A system for integrated optimal design	1985	Design optimization, 259-294	
6.	Design knowledge and sequential plans	1985	Environment and Planning B: Planning and Design 12 (4), 401-418	The application of sequential planning to the design process is discussed, considering design as a search through a space of states which are acted upon by transformation rules. Various approaches to goal satisfaction are considered, including forward inference, regression, the satisfaction of implicit goals, and metaplanning. These issues are illustrated with an example from a simple design domain. The example has been implemented in PROLOG.
	Design prototypes: a knowledge representation schema for design	1990	AI magazine 11 (4), 26-26	
7.	Using logic to represent graphical shapes	1993	AIí93-The Sixth Australian Joint Conference on Artificial Intelligence …	
8.	Computational models of creative design processes	1994	Artificial intelligence and creativity, 269-281	
9.	Formal design methods for computer-aided design	1994	Proceedings of the IFIP TC5/WG5. 2 Workshop on Formal Design Methods for CAD …	
10.	Towards a model of exploration in computer-aided design.	1994	Formal design methods for CAD, 315-336	
11.	Learning genetic representations as alternative to hand-coded shape grammars	1996	Artificial Intelligence in Design'96, 39-57	
12.	Spatial layout planning using evolved design genes	1996	Smart Engineering Systems: Neural Networks, Fuzzy Logic and Evolutionary …	Spatial layout planning is an NT-complete optimization problem. In this paper we apply to it an extension to the Btandard genetic algorithm based on an analog with the genetic engineering of natural systems. This allows not only the solution to evolve but also evolves the genetic representation at the same time producing'evolved genes'. In spatial layout problems these evolved genes map onto spatial compact clusters of activities (spaces). The evolution of these genes can be viewed as a form of learning of problem-specific knowledge related to the structure of the problem being solved. The resulting search process proceeds in two stages. During the first stage these clusters of activities are produced and optimally arranged with respect to each other. During the second stage this' large-scaled layout'is improved by rearranging the activities within each such cluster. It is shown that the genetic engineering extension to genetic algorithms produces results faster than the standard GA. Further, it is demonstrated that the evolved genes can be reused in a class of related problems further increasing the efficiency of the method.
13.	A logic-based framework for shape representation	1996	Computer-Aided Design 28 (3), 169-181	Shapes represent a very important way with which we perceive and reason about the world. In this article we develop a logic-based framework to represent graphical shapes in two dimensions. Based on the concept of halfplanes, this framework allows us to represent regions as predicates in logic. This representation is applied to demonstrate shape concepts associated with topology and emergence.
14.	Shape reasoning in CAD systems	1997	Industrial and Engineering Applications or Artificial Intelligence and …	This paper presents a logic-based representation for shapes and objects which allows topological reasoning, among other features. This representation is suitable to be used in current CAD systems as it can be mapped from a shape's numerical representation.
15.	Qualitative representation of shape and space for computer aided architectural design	1997	CAADRIA 97, 323-334	
16.	Emergent Shape Generation in Design Using the Boundary Contour System	1997	CAAD futures 1997, 865-874	This paper discusses the boundary contour system as the basis of a computational model of emergent recognition applicable in design. Details of this system which make it appealing as a computational approach for emergent recognition are introduced. The performance of a system implementation is covered and an extension to improve its performance is discussed.

17.	Computable feature-based qualitative modeling of shape	1997	CAAD futures 1997, 821-830	This paper introduces and describes a qualitative approach to the modeling of shapes applicable at the early stage of designing. The approach is based on using qualitative codes at landmarks to describe shapes. These strings of codes can be analysed to determine patterns which map onto features. An analogy with language is drawn to assist in articulating the modeling ideas. An example is presented which demonstrates the utility of the approach.
18.	Learning and re-using information in space layout planning problems using genetic engineering	1997	Artificial Intelligence in Engineering 11 (3), 329-334	We describe the use of a genetic engineering version of genetic algorithms as a natural tool for gathering and re-using information about some classes of design problems. This information is stored in the form of sets of 'evolved genes' which are linked to beneficial qualities of the 'good' designs within this class of problems. The approach is illustrated on a space layout planning problem.
19.	Computable Representations of Patterns in Architectural Shapes	1997	CUMINCAD	This paper develops a schema theory based approach to the representation of patterns in architectural shapes. This representation is capable of computer implementation. The adequacy of any representation is critical for information processing in computer-aided design. Shape representation using shape elements and spatial relationships are elaborated and the construction of shape schemas and characteristics of shape schema are investigated. A representation for patterns in architectural shapes is demonstrated.
20.	Shape reasoning in CAD systems	1997	Industrial and Engineering Applications or Artificial Intelligence and …	
21.	A genetic programming approach to the space layout planning problem	1997	CAAD futures 1997, 875-884	The space layout planning problem belongs to the class of NP-hard problems with a wide range of practical applications. Many algorithms have been developed in the past, however recently evolutionary techniques have emerged as an alternative approach to their solution. In this paper, a genetic programming approach, one variation of evolutionary computation, is discussed. A representation of the space layout planning problem suitable for genetic programming is presented along with some implementation details and results.
22.	Shape pattern recognition using a computable pattern representation	1998	Artificial intelligence in design'98, 169-187	Properties of shapes and shape patterns are investigated in order to represent shape pattern knowledge for supporting shape pattern recognition. It is based on the notion that shape patterns are classified in terms of similarity of spatial relationships as well as physical properties. Methods for shape pattern recognition are explained and examples from an implementation are presented.
23.	Space layout planning using an evolutionary approach	1998	Artificial Intelligence in Engineering 12 (3), 149-162	This paper describes a design method based on constructing a genetic/evolutionary-design model whose idea is borrowed from natural genetics. Here, two major issues from the modelling involve how to represent design knowledge for the evolutionary design model and the usefulness of the model for design problems. For the representation of design knowledge in the model, a schema concept is introduced. The utility of the model is based on its computational efficiency and its capability of producing satisfactory solutions for the given set of problem requirements. The design problem used to demonstrate the approach is a large office layout planning problem with its associated topological and geometrical arrangements of space elements. An example drawn from the literature is used.
24.	Shape pattern representation for design computation	1998	Working Paper	
25.	Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions	1998	Design studies 19 (4), 455-483	
26.	Style learning: Inductive generalisation of architectural shape patterns	1999	Proceedings of eCAADe conference, 629-44	
27.	Computational models of innovative and creative design processes	2000	Technological forecasting and social change 64 (2-3), 183-196	
28.	Categorisation of shapes using shape features	2000	Artificial intelligence in design'00, 203-223	We introduce a shape categorisation method for architectural drawings that takes shape characteristics derived from those drawings as features. We propose a feature-based shape analysis procedure and a formal model of shape categorisation based upon the measurement of featural similarity of shapes. Shape categorisation is demonstrated in experiments on architectural drawings.
29.	Computational situated learning in designing: Application to architectural shape semantics	2000	Proc. Sixth Int. Conf. on Artificial Intelligence in Design (AID'00)(Gero …	This paper presents the development of a computational process model of Situated Learning in Design (SLiDe). Situated learning is based on the notion that knowledge is more useful when it is learned in relation to its immediate and active context, ie its situation, and less useful when it is learned out of context. The usefulness of design knowledge is in its operational significance based upon where it was used and applied. SLiDe elucidates how design knowledge is learned in relation to its situation, how design situations are constructed and altered over time in response to changes taking place in the design environment. SLiDe is implemented within the domain of architectural shapes in the form of floor plans to capture the situatedness of shape semantics. SLiDe utilises an incremental learning clustering mechanism not affected by the concept drift that makes it capable of constructing various situational categories and constantly modifying them over time. The paper concludes with a discussion of the potential benefits of using SLiDe during the conceptual stages of designing. 1.
30.	A computational framework for concept formation for a situated design agent	2000	Knowledge-Based Systems 13 (6), 361-368	
31.	Some Recent Computer-Aided Design Research	2000	Computing in Civil and Building Engineering: Proceedings of the …	
32.	Emerging strategic knowledge while learning to interpret shapes	2001	K, Strategic Knowledge and Concept Formation III, Key Centre of Design …	If we describe strategic knowledge at KL and • Ignore origins of knowledge • Ignore how it is represented and used • Then we risk not handling • Autonomous adaption • Changing environments • If strategic knowledge not grounded in agents experiences • Then do we attribute resulting designs to a design agent •… or to its designer?

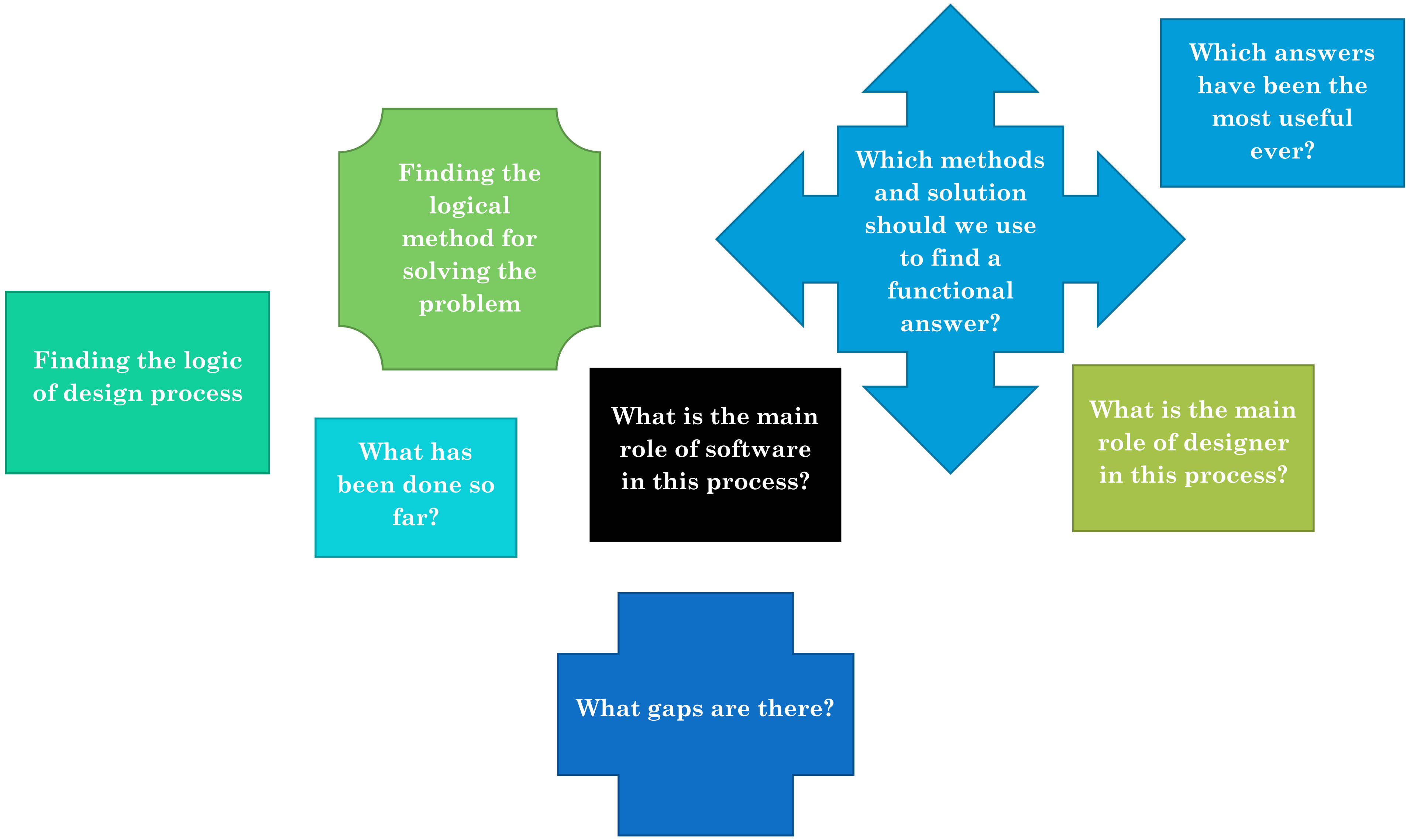
33.	Automated Toolset Selection for Feature Manufacturing	2002	Artificial Intelligence in Design'02, 521-543	
34.	Computational models of creative design situations	2002	Agents in Design, 165-180	
35.	FRAMEWORKS FOR DESIGN	2002	Artificial Intelligence in Design'02, 63	
36.	Measuring the information content of architectural plans	2002	CUMINCAD	This paper describes and develops a preliminary approach to the measurement of the information content of two-dimensional design drawings. We utilise a general method for extracting information from an encoded string of symbols as a canonical representation of architectural plans. The information content of each drawing or set of drawings is determined by measuring its entropy. We present two classes of qualitative representation of shape and space. The first uses a qualitative representation of the outline of shapes in the drawing. The second uses a qualitative representation of the spaces described in the drawing. We describe the preliminary implementation of the method to a time-evolution of two formally described design styles, Romanesque and Gothic cathedral plans.
37.	Feature based qualitative representation of architectural plans	2003	CAADRIA, 117-128	This paper develops an approach to the qualitative representation of architectural plan drawings. We describe a schema for representing the internal shapes features and their associated spatial relations using syntactic pattern and contour specifications. This schema uses a qualitative symbolic representation to detect features. An example application of this representation is presented.
38.	The situated function–behavior–structure framework	2004	Design studies 25 (4), 373-391	
39.	Qualitative representation and reasoning in design: A hierarchy of shape and spatial languages	2004	Visual and Spatial Reasoning in Design III, 139-163	
40.	Automated code checking	2004	https://digitalcollectio ns. qut. edu. au/1661/	Most buildings constructed in Australia must comply with the Building Code of Australia (BCA). Checking for compliance against the BCA is a major task for both designers and building surveyors. This project carries out a prototype research using the EDM Model Checker and the SMC Model Checker for automated design checking against the Building Codes of Australia for use in professional practice. In this project, we develop a means of encoding design requirements and domain specific knowledge for building codes and investigate the flexibility of building models to contain design information. After assessing two implementations of EDM and SMC that check compliance against deemed-to-satisfy provision of building codes relevant to access by people with disabilities, an approach to automated code checking using a shared object-oriented database is established. This project can be applied in other potential areas – including checking a building design for non-compliance of many types of design requirements. Recommendations for future development and use in other potential areas in construction industries are discussed.
41.	Intelligent agents in design	2004	AI EDAM 18 (2), 113-113	
42.	A framework for situated design agents	2005	CUMINCAD	
43.	How to make design optimization more useful to designers	2005	ANZAScA 2005	This paper presents an approach to making design optimization tools more useful to designers. Design optimization is the selection of the best design solution from alternative solutions to a given problem. Design optimization tools require that all the variables, parameters, goals and constraints be defined prior to the execution of any optimization process. This narrows the scope of design optimization, as the user has to reformulate the problem if any of these change during the designing process. The situatedness paradigm in design proposes the interactions and processes between the designer/design tool and the environment as the basis for designing. A design system based on the situatedness paradigm can handle changing variables and constraints, and can reconfigure the solution space based on an assessment of the current conditions. This paper proposes an alternate approach to design optimization based on the situatedness paradigm, where an adaptive situated optimization framework can automate the task of problem and solution reformulation as part of the optimization process to produce better solutions. The framework is demonstrated through an example using genetic algorithms as an optimization technique.
44.	Digital Design, Representation and Visualization	2005	Computer Aided Architectural Design Futures 2005: Proceedings of the 11th …	
45.	To sketch or not to sketch? That is the question	2006	Design studies 27 (5), 587-613	
46.	A SELF-TRAINING SYSTEM THAT LEARNS THROUGH EXPERIMENTATION	2006	DS 36: Proceedings DESIGN 2006, the 9th International Design Conference …	
47.	Spatial Cognition in Architectural Design	2007	Bremen, Germany	
48.	Re-thinking Optimization as a Computational Design Tool: A Situated Agent Approach	2007	Proc. Computer Aided Architectural Design Research in Asia	
49.	A cognitive and computational basis for designing	2007	DS 42: Proceedings of ICED 2007, the 16th International Conference on …	
50.	Computer-aided design tools that adapt	2007	Computer-Aided Architectural Design Futures (CAADFutures) 2007, 417-430	

51.	Context and design agents	2007	International and Interdisciplinary Conference on Modeling and Using Context …	Informal notions of context often imply much more than that captured in many computational formalisms of it. The view presented in this paper, built on our understanding of designing, is of context being larger than any one agent's representation of it. This paper describes how for an agent's reasoning about context it is the current situation that determines what the agent's interpretations of context are, not the reverse. The paper presents a typical scenario involving collaborating, sketching designers.
52.	Design Computing and Cognition	2007	AI EDAM 21 (4), 315-316	
53.	How can CAAD tools be more useful at the early stages of designing? Towards Situated Agents That Interpret	2008	Chiang Mai University	
54.	Learning symbolic formulations in design optimization	2008	Design Computing and Cognition'08, 533-552	
55.	Situated Computation	2009	Proceedings of the 2009 conference on New Trends in Software Methodologies …	
56.	Directions for Design Creativity Research (Invited Papers)	2010	Design Creativity 2010, 1	
57.	Exploring quantitative methods to study design behavior in collaborative virtual workspaces	2010	New Frontiers, Proceedings of the 15th International Conference on CAADRIA	This paper presents a case of exploring and applying quantitative tools to examine design protocol in a collaborative virtual environment. After introducing the motivation, a design ontology along with two methods of analysis are depicted as a foundation for this investigation. The case data of a virtual design session is presented which has been examined together with its counterpart face-to-face design session that act as a base-line. In this case the 3D virtual environment slows down the design activities and it also has an inclination to favor certain design activities.
58.	Studying designers' behaviour in collaborative virtual workspaces using quantitative methods	2010	15th International Conference on Computer-Aided Architectural Design in Asia …	
59.	Constructive interpretation with examples from interpreting floor plans	2011	Proceedings of the 16th International Conference on Computer-Aided …	This paper describes the role that interpretation plays in facilitating situated design and presents an implementation that demonstrates a system interpreting floor plans. Designers often see more in what they produce than they intentionally put there. Cognitive studies suggest that this helps develop design ideas. Interpretation is described as the use of expectations to construct an internal representation of an external representation (such as a sketch). An implementation of this notion of interpretation is described. As an example of its capability the system, primed on floor plans, looks at a randomly generated image and can find a floor plan within it. The system produces different results with the same image if it has different expectations. This is used to discuss the notions of a space of possible designs and the two-way relationship between expectations informing interpretation and interpretation changing the expectations (design ideas) of a designer. Further work is suggested and the ideas are discussed.
60.	A framework for constructive design rationale	2011	Design Computing and Cognition'10, 135-153	
61.	Design creativity	2012	Journal of Engineering Design 23 (4), 237-239	
62.	Multicriteria optimization in architectural design	2012	Design Optimization, 229	
63.	Frank Lloyd Wright: Transforming	2012	Adaptive Computing in Design and Manufacture: The Integration of …	
64.	Reversal of a shape grammar for indexing and retrieval	2012	Artificial Intelligence in Design'00, 225	Generative systems are capable of producing a consistent and comprehensive collection of patterns that meet certain constraints by means of formal components, which make explicit the primitive parts of the patterns of this collection, the allowed relations between primitive parts and underlying geometric reference frames. This explicitness suggests that generative systems can be reversed in purpose, that is, applied to the task of describing the patterns they produce. A reversed generative system describes a pattern by the sequence of steps used to generate an image (shape code). This shape code combines explicitness of potentially all image features with flexibility in retrieval and classification and with reduction of dimensionality. Description of an image by its shape code relates to cognitive theories of perception and recognition, notably recognition-by-components and the structural information theory. As an example of the application of such formalisms to the representation of architectural images the paper describes a reversal of the Palladian grammar's room layout rule system into a compact representation of spatial arrangement. This representation can be applied to the indexing and retrieval of Palladian floor plans.
65.	Design optimization	2012	Elsevier	
66.	DESIGNING A FONT TO TEST A THEORY	2012	Artificial Intelligence in Design'00, 3	
67.	STRATEGIC SHAPE DESIGN	2013	Artificial Intelligence in Design'02, 371	Although many attempts have been made to enable creative and effective design activities using a computer, many design activities depend on the designer's personal ability and are learned through interpersonal communication. These limitations are thought to be due to the fact that the knowledge we use does

				not cover the entire design process, comprising the problem-forming process and the problemsolving process, in a systematic manner. In this study, a method of dealing with the design information, in which the problem-forming process is considered, and dealt with simultaneously the problem-Solving process, is proposed. This method is composed of three steps:(1) determination of the evaluation function from the shape,(2) synthesis (composition) of the evaluation function, and (3) generation of the shape candidates from the evaluation function. Interaction with a computer system implementing this method is expected to assist the shape design at an early stage. In this study, this method is developed and realized in a computer system.
68.	The creative value of bad ideas: A computational model of creative ideation	2013	Association for Computer-Aided Architectural Design Research in Asia …	
69.	Modeling creativity and knowledge-based creative design	2013	Psychology Press	
70.	Experiential Influences on Computational Association in Design	2013	CUMINCAD	
71.	STRATEGIC SHAPE DESIGN	2013	Artificial Intelligence in Design'02, 371	
72.	ANALYSIS OF ARCHITECTURAL SPACE COMPOSITION USING INDUCTIVE LOGIC PROGRAMMING	2013	Artificial Intelligence in Design'02, 131	
73.	Studying Software Design Cognition	2013	Software Designers in Action: A Human-Centric Look at Design Work, 59	
74.	Exploring designing styles using a problem–solution index	2014	Proc. Design Computing and Cognition '12 (Gero, JS, Ed	
75.	Design Cognition and Computing'12	2014	Springer	
76.	Cognitive effects of using parametric modeling by practicing architects: a preliminary study	2014	Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of …	
77.	Multi-dimensional creativity: a computational perspective	2015	Taylor & Francis	
78.	Cognitive Design Computing	2017	Sharing of Computable Knowledge!, 37	This talk describes the foundational concepts of cognitive design computing and then presents some examples. Cognitive computing is concerned with modeling human cognition computationally and using that model as the foundation for constructing computer models of design activities. Human cognition is based on perception, learning and adaptation. Here we present human cognition in terms of situated cognition-cognition involving interaction with an environment. The talk briefly introduces a set of principles for cognitive design computing founded on the three concepts of interaction, constructive memory and situatedness. It then presents two examples of applications of this approach.
79.	Ekphrasis as a design method	2017	DS 87-7 Proceedings of the 21st International Conference on Engineering …	
80.	This paper describes the procedures involved in the develop	2017	CAD82: 5th International Conference and Exhibition on Computers in Design …	
81.	Ekphrasis as a Basis for a Framework for Creative Design Processes	2018	International Conference on-Design Computing and Cognition, 265-283	This paper introduces the notion of ekphrasis in the arts as a basis for developing a framework of creative designing. Ekphrasis is the transformation of a concept from one medium or domain (e.g. sculpture) to another medium or domain (e.g. music). When used in design, ekphrasis enables the use of new processes afforded within the new domain that can produce new concepts not available in the original domain. We show how five known mechanisms of creative designing—emergence, analogy, combination, mutation and first principles—can be included in a general framework as instantiations of ekphrasis. This framework is developed based on the function–behaviour–structure (FBS) ontology and its application to affordances.
82.	Patterns of Cortical Activation When Using Concept Generation Techniques of Brainstorming, Morphological Analysis, and TRIZ	2018	ASME 2018 International Design Engineering Technical Conferences and …	
83.	Exploring the Differences Between Designing and Describing Designing	2018	Design Theory Research Symposium 12	

84.	Situated novelty in computational creativity studies	2019	10th International Conference on Computational Creativity ICCC19	This paper furthers the study of creative design by taking a situated view of novelty. A set of computational experiments is performed utilizing an agent-based model of a design team, and resulting data is used to examine the influence of a change in a situation (or a design frame) on the perception of a design's novelty in terms of its difference from existing or possible designs. The experiments demonstrate that, over the course of designing, solutions which were regarded as novel, can become not novel. They also show that a solution which was not seen as novel in one situation can be assessed as novel when a situation changes. The results, therefore, emphasize the importance of studying novelty as a situated measure.
85.	The effect of design education on creative design cognition of high school students	2019	International Journal of Design Creativity and Innovation, 1-17	
86.	A computational study of the effect of experience on problem/solution space exploration in teams	2019	Proceedings of the Design Society: International Conference on Engineering …	This paper presents the results of computational experiments aimed at studying the effect of experience on design teams' exploration of problem-solution space. An agent-based model of a design team was developed and its capability to match theoretically-based predictions is tested. Hypotheses that (1) experienced teams need less time to find a solution and that (2) in comparison to the inexperienced teams, experienced teams spend more time exploring the solution-space than the problem-space, were tested. The results provided support for both of the hypotheses, demonstrating the impact of learning and experience on the exploration patterns in problem and solution space, and verifying the system's capability to produce the reliable results.
87.	The situated function-behavior-structure co-design model	2019	CoDesign, 1-26	

In Design Process We Encounter With Some Main Parts



Dr Gero's research is based on the notion that designing is itself a meta-discipline practiced in multiple disciplines such as software design, hardware design, engineering, architecture, and industrial design. His research in design as a meta-discipline commenced with the development of models informed by the formal languages of optimization, artificial intelligence and computational constructs. The validation and simulation of these models has been advanced by cognitive studies of designers across multiple disciplines and has led to an integrated approach of design computing and design cognition. His current research focuses on computational creativity, situated computation, computational social science and the cognitive effects and outcomes of education, practice and experience.

Table 9: Comparison Table for Different Space Layout Planning Approach

	Arvin and House (1990: p 245-262)	Hsu (2000: p 2-3)	Elezkurtaj and Franck (1999: p 645-651 ; 2000: 309- 312)	Li, Frazer and Thang (2000: 441-450)	Michalek choudhary and papalambros (2002; 461-484.)	Hsu and krawczyk (2003: 101-116)	Duarte (2003: 665- 674)	Keatruangkamala and Sinapiromsaram (2005: 175-184)	Lömker (2006: 88-106)	Nilkaew (2006: 641-643)	Doulgerakis (2007: 84)	Donath and Gonzalez (2008: 97-117)	Medjoub and Yannou (2001: 47-60)	Del Rio (2007: 3457-3476)	Mathematica	Average
Approach number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Science																
Engineering			×	×	×	×		×	×	×		×	×	×	×	11
Mathematics							×								×	2
Physics	×															1
Medicine											×					1
Architecture		×	×	×		×	×			×		×	×	×	×	10
Approach																
Expert Systems						×		×						×		3
Generative (GA & EA)			×		×					×	×		×	×		6
Shape Grammars							×									1
Constraint Based		×		×	×	×		×	×			×	×		×	9
Graph Approach													×			1
Mixed Approach								×			×					2
Others (Agents, Physic)	×										×					2
Implementation																
Linear Programming								×	×					×	×	4
Non Linear programming				×					×							2
Gradient Based Algorithms				×	×									×		3
Genetic Algorithms			×							×	×					3
Integer Programming								×	×							2
Differential Equations	×															
Mathematical Equations						×			×			×				3
Drawing Techniques						×			×							2
Boundary use																
Yes			×	×			×		×		×	×	×	×		8
No	×	×			×	×		×		×					×	7

Table 11: Comparison table for commercial BIM software

Comparison Table for Commercial BIM Software									
	Boundary	Spaces	Areas	Topology	Sizes parameters	Options	Automatic Generation	Space creation without walls	Spaces creation from list of rooms
Archicad 9.0	√	√	-	×	×	×	×	×	×
Autodesk Revit 2008	√	√	×	×	√	√	×	√	×
Bentley Architecture (Microstation v8)	-	√	-	×	-	-	×	√	×
Allplan BIM 2008	-	√	-	×	-	-	×	×	×
Architecture Desktop 2007	√	√	√	×	√	×	×	√	×
Digital Project Designer	√	√	-	×	-	-	×	×	×
√ (Allowed), - (Unknown), × (Not allowed)									

Table 15: Sorting the angles between forces of square and equal triangle (Ahmadzadeh siyahroodA, EbrahimiB& Mohammadjavad Mahdavinejad, 2017)

Shape	Internal	External
Square	45	45+45=90
	90	45+45+45=135
		45+45+45+45=180
		45+45+45+45+45=225
		45+45+45+45+45+45=270
		45+45+45+45+45+45+45=315
		45+45+45+45+45+45+45+45=360
Triangle (Equilateral triangle)	30	30+30=60
	60	30+30+30=90
		30+30+30+30=120
		30+30+30+30+30=150
		30+30+30+30+30+30=180
		30+30+30+30+30+30+30=210
		30+30+30+30+30+30+30+30=240
		30+30+30+30+30+30+30+30+30=270
		30+30+30+30+30+30+30+30+30+30=300
		30+30+30+30+30+30+30+30+30+30+30=330
		30+30+30+30+30+30+30+30+30+30+30+30=360
Circle	Omitted	Omitted
Combination of Square and triangle		105
		75
		15
		45
		60
		30
		120
		150
		30+75+105=210
		135
		345

1. *References*

- Abas, S. J. (2001). Islamic geometrical patterns for the teaching of mathematics of symmetry. *Symmetry: Culture and Science*, *12*(1-2), 53-65.
- Abas, S. J., & Salman, A. (1992). Geometric and Group-theoretic Methods for Computer Graphic Studies of Islamic Symmetric Patterns. In *Computer Graphics Forum* (Vol. 11, No. 1, pp. 43-53). Blackwell Science Ltd.
- Ahmed, S. (2012). Applications of graph coloring in modern computer science. *International Journal of Computer and Information Technology (IJCIT)*, *3*, 1-7.
- Alexander, C., Black, G., & Tsutsui, M. (1995). *The Mary Rose Museum* (Vol. 8). Oxford University Press, USA.
- Aljamali, A. M., & Banissi, E. (2004). Grid method classification of Islamic geometric patterns. In *Geometric Modeling: Techniques, Applications, Systems and Tools* (pp. 233-254). Springer Netherlands.
- Andaroodi, E., Andres, F., Einifar, A., Lebigre, P., & Kando, N. (2006). Ontology-based shape-grammar schema for classification of caravanserais: a specific corpus of Iranian Safavid and Ghajar open, on-route samples. *Journal of Cultural Heritage*, *7*(4), 312-328.
- Arbib, M. (2005). Modules, brains and schemas. *Formal Methods in Software and Systems Modeling*, (pp. 153-166).
- Baer, E. (1998). *Islamic ornament*. Edinburgh University Press.
- Benelli, F. (2015). Rudolf Wittkower versus Le Corbusier: A Matter of Proportion. *Architectural Histories 3*(1),3&5.
- Bier, C. (2015). 3 Geometry made manifest. *The Historiography of Persian Architecture*, *29*, 41.
- Boon, P. (2006). Designing didactical tools and micro-worlds for mathematics education. In *C. Hoyles, JB Lagrange, LH Son, & N. Sinclair, Proceedings of the 17th ICMI Study Conference*.
- Bordoloi, S., & Kalita, B. (2013). Designing graph database models from existing relational databases. *International Journal of Computer Applications*, *74*(1).
- Bork, R. (2014). Dynamic Unfolding and the Conventions of Procedure: Geometric Proportioning Strategies in Gothic Architectural Design. *Architectural Histories 2*(1), 8& 14
- Bork, R. (2014). The Geometry of Bourges Cathedral. *Architectural Histories*, *2*(1),23.
- Broug, E. (2008). *Islamic geometric patterns*. London: Thames & Hudson ,2-3.
- Burgin, M. (2005). Mathematical Models in Schema Theory. arXiv preprint cs/0512099.
- Çağdaş, G. (1996). A shape grammar model for designing row-houses. *Design Studies*, *17*(1), 35-51.
- Chorbachi, W. A. K. (1989). In the Tower of Babel: Beyond symmetry in Islamic design. *Computers & Mathematics with applications*, *17*(4-6), 751-789.
- Critchlow, K. (1976). *Islamic patterns*. Thames and Hudson.
- Dabbour, L. M. (2012). Geometric proportions: The underlying structure of design process for Islamic geometric patterns. *Frontiers of Architectural Research*, *1*(4), 380-391.
- Del Río-Cidoncha, G., Martínez-Palacios, J., & Iglesias, J. E. (2007). A multidisciplinary model for floorplan design. *International journal of production research*, *45*(15), 3457-3476.
- Deswal, S., & Singhrova, A. (2012). Application of Graph Theory in Communication Networks. *International Journal of Application or Innovation in Engineering & Management*, *1*(2), 66-70.
- Di Teodoro, F. (2015). Leonardo da Vinci: The Proportions of the Drawings of Sacred Buildings in Ms. B, Institut de France. *Architectural Histories*, *3*(1), 2&4.
- Donath, D., & Böhme, L. F. G. (2008). Constraint-based design in participatory housing planning. *International Journal of architectural computing*, *6*(1), 97-117.
- Doulgerakis, A. (2007). Genetic and Embryology in Layout Planning. *Master of Science in Adaptive Architecture and Computation, University of London*., 84 p.
- Duarte, J. P. (2003). Customizing mass housing: A discursive grammar for Siza's Malagueira houses (Alvaro Siza, Portugal), 665-674.
- Durán, R., & Rico, R. (2006). On applying graph theory to ILP analysis. *IEEE Latin America Transactions*, *4*(4), 291-298.
- Ekhtiar, M. (2011). *Masterpieces from the Department of Islamic art in the Metropolitan Museum of Art*. Metropolitan Museum of Art. New York.
- Elezkurtaj Arvin, S. A., & House, D. H. (1999, January). Making designs come alive: using physically based modeling techniques in space layout planning. *Computers in building: proceedings of the CAAD futures' 99 Conference: proceedings of the Eighth International Conference on Computer Aided Architectural Design Futures held at Georgia Institute of Technology (*pp: 245-262), Atlanta, Georgia, USA on June 7-8, : Kluwer Academic Publishers.
- Elezkurtaj, T., & Franck, G. (1999). Genetic algorithms in support of creative architectural design. *European Computer Aided Architectural Design and E* 17, 645-651.
- El-Said, I., El-Bouri, T., & Critchlow, K. (1993). *Islamic art and architecture: the system of geometric design*. Garnet Pub Ltd.
- Ettinghausen, R., Grabar, O., & Jenkins, M. (2001). *Islamic art and architecture 650-1250* (Vol. 51). Yale University Press.
- Gero, J.S. (1977). Note on "Synthesis and optimization of small rectangular floor plans" of Mitchell, Steadman, and Liggett. Environment and Planning B, 4, 81-88.
- Grzesiak-Kopeć, K., Oramus, P., & Ogorzałek, M. (2015). Using shape grammars and extremal optimization in 3D IC layout design. *Microelectronic Engineering*, *148*, 80-84.
- Gürsoy, B., & Özkar, M. (2015). Visualizing making: shapes, materials, and actions. *Design Studies*, *41*, 29-50.
- Harrison, L., Earl, C., & Eckert, C. (2015). Exploratory making: Shape, structure and motion. *Design Studies*, *41*, 51-78.
- Hillenbrand, R. (1999). *Islamic art and architecture*. London: Thames and Hudson.
- Hsiao, S. W., & Chen, C. H. (1997). A semantic and shape grammar based approach for product design. *Design studies*, *18*(3), 275-296.
- Hsu, Y. C., & Krawczyk, R. (2004). Form Development with Spatial Character. *European Ccomputer Aided Architectural Design and Education* 18, 278-285
- Hsu, Y. C., & Krawczyk, R. J. (2003). New generation of computer aided design in space planning methods: A survey and a proposal. *Computer Aided Architectural Design and Research in Asia, Bangkok. Proceedings... Bangkok*, 101-116.

- Hsu, Y. C., & Krawczyk, R. J. (2003). New generation of computer aided design in space planning methods: A survey and a proposal. *Computer Aided Architectural Design and Research in Asia, Bangkok. Proceedings... Bangkok*, 101-116.

- Jebelean, T., Buchberger, B., Kutsia, T., Popov, N., Schreiner, W., & Windsteiger, W. (2009). Automated Reasoning. *In Hagenberg Research* (pp. 63-101). Springer, Berlin, Heidelberg.
- Johnson, H. T., & Broms, A. (2000). *Profit beyond measure: Extraordinary results through attention to work and people* (p .196). Simon and Schuster.
- Johnson, P. A. (1994). *The Theory of Architecture: Concepts Themes & Practices* (p.357). John Wiley & Sons.
- Kaplan, C. S. (2000). Computer generated Islamic star patterns. *Bridges*, 105-112.
- Kaplan, C. S. (2005, May). Islamic star patterns from polygons in contact. In *Proceedings of graphics interface 2005* (pp. 177-185). Canadian Human-Computer Communications Society.

- Kaplan, C. S., & Salesin, D. H. (2004). Islamic star patterns in absolute geometry. *ACM Transactions on Graphics (TOG)*, *23*(2), 97-119.
- Kappraff, J. (2001). *Connections: the geometric bridge between art and science* (Vol. 25). World Scientific.
- Keatruangkamala, K., & Sinapiromsaram, K. (2005). Optimizing Architectural Layout Via Mixed Integer Programming. *CAAD FUTURES* 11, 175-184.
- Knight, T., & Stiny, G. (2015). Making grammars: From computing with shapes to computing with things. *Design Studies*, *41*, 8-28.
- Kreitz, C. (1999). Cognitive Studies Proseminar (Cogst 773), Cornell University, Fall (Slides of October 5 lecture) (http://www.cs.cornell.edu/home/kreitz/teaching/courses.html)
- Lee, A. J. (1987). Islamic star patterns. *Muqarnas*, *4*, 182-197.
- Li, S. P., Frazer, J. H., & Tang, M. X. (2000). A constraint based generative system for floor layouts, 441-450.
- Lömker, T. M. (2006). Designing with Machines: solving architectural layout planning problems by the use of a constraint programming language and scheduling algorithms, 88-106.
- Mahdavinejad, M., Ahmadzadeh Siyahrood, S., Ghasempourabadi, M., & Poulad, M. (2012). Development of Intelligent Pattern for Modelling a Parametric Program for Public Space (Case study: Isfahan, Mosalla, Iran). *Applied Mechanics and Materials* 220, 2930-2935.
- Manjula, V. (2012). Graph Applications to Data Structures. *Advanced Materials Research* 433, 3297-3301.
- Mary B. McVee, Kailonnie Dunsmore and James R. Gavelek, Review of Educational Research. Vol. 75, No. 4 (Winter, 2005), pp. 531-566
- Medjdoub, B., & Yannou, B. (2001). Dynamic space ordering at a topological level in space planning. *Artificial Intelligence in engineering*, *15*(1), p: 47-60.
- Medjdoub, B., & Yannou, B. (2001). Dynamic space ordering at a topological level in space planning. *Artificial Intelligence in engineering 15*(1), 47-60.
- Michalek, J., Choudhary, R., & Papalambros, P. (2002). Architectural layout design optimization. *Engineering optimization*, *34*(5), 461-484.
- Molodi, B. (2002). Application of geometry in Architecture of Iran's past: Tehran: Building and housing research center.
- Nazidizaji, S., Tomé, A., & Regateiro, F. (2015). Does the smartest designer design better? Effect of intelligence quotient on students' design skills in architectural design studio. *Frontiers of Architectural Research* 4, 318-329.
- Nilkaew, P. (2006). Assistant Tool for Architectural Layout Design by Genetic Algorithm, 641-643.
- Nishizeki, T., Tamassia, R., & Wagner, D. (1998). *Graph algorithms and applications*. Schloss Dagstuhl.
- Nourian, P., Rezvani, S., & Sariyildiz, S. (2013). A synthetic architectural design methodology: Integrating real-time space syntax analysis in a configurative architectural design process. In K. Yo, HT.Park &KW.Seo Paper 48 (Ed.), *Proceedings of Ninth International Space Syntax Symposium, October 31-November 3, 2013, Seoul, Korea:* Sejong University Press.
- Oxman, R. (2017). Parametric design thinking.
- Prévost, R., Whiting, E., Lefebvre, S., & Sorkine-Hornung, O. (2013). Make it stand: balancing shapes for 3D fabrication. *ACM Transactions on Graphics (TOG)*, *32*(4), 81.
- Pupo, R., Pinheiro, E., Mendes, G., Kowaltowski, D. C. C. K., & Celani, G. (2007). A design teaching method using shape grammars. *Proc. 7th Int. Conf. Graphics Engineering for Arts and Design*,1-10, 3
- Riabov, V. V. (2007). Graph theory applications in developing software test strategies for networking systems. *The Rivier Academic Journal* 3(1).
- Rumelhart, D.E. (1980). *Schemata: The building blocks of cognition*. In RJ, Spiro, BC, Bruce, WF Brewer, (Eds.), Theoretical issues in reading comprehension: Perspectives from cognitive psychology, linguistics, artificial intelligence, and education. Hillsdale, NJ: Erlbaum.
- Shirinivas, S. G., Vetrivel, S., & Elango, N. M. (2010). Applications of graph theory in computer science an overview. *International Journal of Engineering Science and Technology 2*(9), 4610-4621.
- Siyahrood, S. A., Ebrahimi, A., & Mahdavinejad, M. (2017). Generating a Functional Grammar for Architectural Design from Structural Hierarchy in Combination of Square and Equal Triangle. *World Academy of Science, Engineering and Technology, International Journal of Architectural and Environmental Engineering*, *4*(12).
- Tavasoli, M. (2004). *Art of Geometry* (pp. 5-15). Tehran: Payam, first print.
- Trescak, T., Esteva, M., & Rodriguez, I. (2012). A shape grammar interpreter for rectilinear forms. *Computer-Aided Design*, *44*(7), 657-670.
- Wade, D. (1976). *Pattern in Islamic art*. Studio Vista.
- White, E. T. (1975). *Concept sourcebook: A vocabulary of architectural forms* (p.193). Tucson: Ariz Architectural Media.
- Williams, R. (1971). On the application of graph theory to computer data structures. *Advanced Computer Graphics*, Springer US, 775-801.