Artificial Intelligence for Engineering Design, Analysis and Manufacturing

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Design computing and cognition

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Guest Editorial

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Design Computing and Cognition has been through the years a recurring topic of AI EDAM special issues. A regular stream of articles is constituted by updated and extended versions of papers presented at the homonymous conference, the International Conference on Design Computing and Cognition (http://dccconferences.org/). Accordingly to such tradition, the call for this special issue was planned, which was launched after the 2018 edition, namely the Eight of the series, held at Politecnico di Milano, Italy, in the Lecco Campus on July 2–4, 2018.

This special issue embeds, therefore, a selection of suitably extended and updated papers that were presented at DCC'18 and are complemented by further contributions aimed to depict the state-of-the-art research and some relevant trends in this domain.

The scope of this research domain is indeed quite broad, but it inherits its breath from the holistic role that Design has in the evolution of society. The need for designing is led by a society's view that intends Design as a means to improve or add value to human existence well beyond simple subsistence. Everything potentially could be designed from scratch or improved, every time the world around us is unsuited to our needs. In this sense, the world is increasingly "artificial" rather than a naturally occurring one. Designing is a fundamental precursor to manufacturing, fabrication, construction, or implementation, and Design is a primarily important topic in disciplines ranging from the more commonly associated fields of Engineering, Computer Science and Architecture, to emerging areas in the social and life sciences.

The growth of awareness about the fundamental importance of "designing" changes in all dimensions of society is accompanied by the increased rigor of research in Design, but also by the differentiation of research motivations and objectives. With the aim of introducing the papers of this special issue, but also to frame the research objectives and methods that emerged from this selection and by the observation of further publications in the Design domain, we refer here to three complementary dimensions which concur to the classification of research activities in design with respect to their motivation, methodological approach, and working data.

The first dimension refers to the *research intent* and follows the three epistemological interpretations of the relationships between science and design introduced by Cross (2001): scientific design, design science, and a science of design:

- *scientific design* refers to modern, industrialized design and employs scientific knowledge resulting from natural and social sciences – both fundamental and applied – to engineering and architecture;
- *design science* has the aim of developing scientifically-based, domain-independent, explicitly organized, rational, and systematic methods and tools to improve the design action;
- *science of design* views the design process as a phenomenon to be studied scientifically, that is, with systematic and reliable methods of investigation, assuming academic perspectives that range from psychology to ethnography and from cognitive to organizational science.

All these three classes get benefit from a more profound understanding of design cognition or through the support of computational models, but different approaches and techniques generally characterize the research endeavor. These differences can be recognized also in the papers of this special issue.

A first difference can be traced onto the *logical approach underlying the research* and can be schematically represented by the duality between *empirical* and *normative* research. Empirical approaches start with the design and the execution of experiments that allow to test hypotheses or to recognize regularities and patterns with inductive logic. Cognitive science largely adopts this approach that propagated in many branches of design research, as in the majority of studies on Human Behaviour in Design (HBiD).

Similarly, in the computational domain, design research can be carried out by conjecturing design processes, constructing computational models of those processes, and then examining the behaviors of the resulting computational systems in simulated experiments. On the other hand, normative research is carried out by positing axioms or prescriptive rules and then deriving consequences from them with deductive reasoning. If the axioms/rules can be

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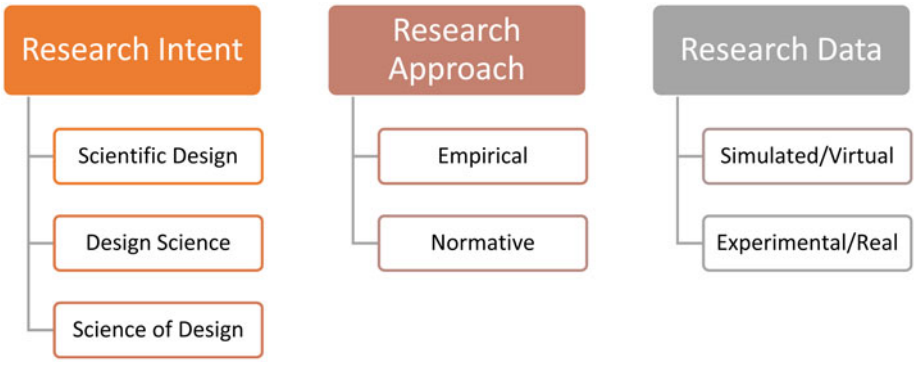


Fig. 1. Classification scheme for design-related research papers.

mapped onto design situations, then the consequences are systematically and rigorously derived. Often normative research demonstrates the validity of the proposed prescriptions by means of validation tests that could be based on experimental data or simulations.

The second difference results from the *data adopted to carry out research activities* and inform design decisions. Both empirical and normative research can build on simulated/virtual data deriving from computational models or on "real" data collected on the field.

By combining these factors, we could classify design research approaches by distinguishing between empirical and normative approaches, as well as between based on simulated/virtual or experimental/real data, as depicted in Figure 1.

The papers of this special issue evenly span over the classes of the proposed framework and provide a representative picture of the research ongoing in the domain of design computing and cognition.

Starting with a first cluster of three papers aiming at the creation of methods and tools to improve the design action, that is, contributing to Design Science, the first contribution is proposed by Miriam Lester *et al.*: "Using evolutionary algorithms to select text features for mining design rationale". Specifically, the authors propose statistical text-mining as a means to identify the design rationale, which underlies all the decisions made in the design process. Despite the recognized value of explicit design rationale that enables efficient reuse of design information, its ex-post elicitation is typically considered extremely time-consuming. Therefore, the authors define a computational experiment, specifically applied to software bug reports and design discussion transcripts for the design rationale identification, by comparing two evolutionary algorithms for feature selection, Ant Colony Optimization and Genetic Algorithms, with respect to classifiers without feature selection. In a more general perspective, the development of text-mining algorithms for eliciting the rationale behind design decisions appears as a research stream of paramount importance to bring Artificial Intelligence (AI) systems a step ahead toward their diffusion as design support.

The second paper, "Design characteristics and aesthetics in evolutionary design of architectural forms directed by fuzzy evaluation" by Mars *et al.*, also contributes to the definition of design supporting tools, but rather follows a normative approach driven by Irving Biederman's recognition-by-components theory to identify three-dimensional structural components of the design object, in this case buildings. The proposed evolutionary algorithm generates multiple design structures afterwards evaluated and selected through an adaptation of Birkhoff's aesthetic measure underlying the fitness function. This research raises the bar for computer-aided architectural design toward the implementation of intelligent systems capable to mirror the human way of thinking and sense of aesthetics in the design process.

An established trend in Design consists in the involvement of end-users in the design process as a means to properly recognize their wishes and expectations. End-users' participation in design activities turns out to be extremely relevant especially when aiming at mass customization. Clearly, the involvement of non-designers in the design process also implies serious difficulties due to their lack of experience and capability to figure out the consequences of the design choices. The above challenge is addressed in the third paper, "Enabling parametric design space exploration by non-designers" by Castro e Costa *et al.* that proposes a rule-based modeler combined with a design navigator. The former enables designers to create customizable designs in the form of parametric models that can be manipulated by end-users by controlling parametric configurations in the navigator module. The navigator limits the exploration of design variants within the limits of viable configurations and could be connected to a digital fabrication machine to finalize the mass customization process. Also, in this case, we recognize a normative approach to research, but the validation of the usability of the proposed system and the analysis of the user-experience is carried out with experimental data collected in pilot tests with undergraduate and graduate students.

The second cluster of the special issue includes four papers that can be classified as contributions in the area of Scientific Design. Liu and Kaneda open this second series of papers with "Using agent-based simulation for public space design based on the Shanghai Bund waterfront crowd disaster". Specifically, they use agent-based simulation to study the effect on crowd safety of obstacles in a bottleneck area of public open space. The outcomes of the study allow making hypotheses about spatial layouts and evacuation plans, using the Shanghai Bund as a case study. A general lesson learned from this contribution concerns the scientific elaboration of past events, for example, a previous disaster, as a means to improve building architecture and space design so as to prevent the repetition of failures.

Data from the past are used also by Mamoli in "A shape grammar for the building-type definition of the ancient Greek and Roman library and the evaluation of library plans". In this case, a corpus of 17 libraries from the Hellenistic and Roman times is analyzed to build a set of rules from their plans, sections, and other archeological data. The proposed design grammar allows generating a broad range of variants from the simplest to the most monumental buildings but could be applied also for

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Table 1. Exemplary classification of the papers of the special issue according to Figure 1 framework

	Scientific Design	Design Science	Science of Design
Empirical Research	4, 5, 6	1	8, 9
Normative Research	7	2, 3	10
Simulated/Virtual Data	4, 6, 7	1, 2	–
Experimental/Real Data	5	3	8, 9, 10
Running Order	Authors	Article Title	
1	Lester, M., Guerrero, M., & Burge, J.	Using evolutionary algorithms to select text features for mining design rationale	
2	Mars, A., Grabska, E., Slusarczyk, G., & Strug, B.	Design characteristics and aesthetics in evolutionary design of architectural forms directed by fuzzy evaluation	
3	Castro e Costa, E., Jorge, J., Knochel, A., & Duarte, J.	Enabling parametric design space exploration by non-designers	
4	Liu, Y. & Kaneda, T.	Using agent-based simulation for public space design based on the Shanghai Bund waterfront crowd disaster	
5	Mamoli, M.	A shape grammar for the building-type definition of the ancient Greek and Roman library and the evaluation of library plans	
6	Liu, X. & Jin, Y.	Reinforcement learning based collision avoidance: impact of reward function and knowledge transfer	
7	Kahlon, Y. & Fujii, H.	Framework for metaphor-based spatial configuration design: a case study of Japanese rock gardens	
8	Huang, W., Su, X., Wu, M., & Yang, L.	Category, process and recommendation of design in an interactive evolutionary computation interior design experiment: a data-driven study	
9	Borgianni, Y. & Maccioni, L.	Review of the use of neurophysiological and biometric measures in experimental design research	
10	Koskela, L. & Kroll, E.	Demonstration, extension and refinement of the re-proposed notion of design abduction	

reconstructing fragmentarily preserved ancient libraries. In a more general perspective, this paper is a nice example of design knowledge formalization from the analysis of an adequate number of past instances. Such formalized knowledge can then be embedded in design automation tools to perform design tasks or to support decision-making in Design.

Design knowledge can be elicited from past experiences or can be built through simulated scenarios. It's the case of the sixth paper by Liu and Jin, "Reinforcement learning based collision avoidance: impact of reward function and knowledge transfer", a study in the field of autonomous vehicles, specifically ships, capable not only of steering in open waters but also of avoiding collisions in congested harbors and reaching alongside berths without direct human involvement. Through deep learning, artificial systems can learn from humans' operation experiences (e.g., through supervised deep learning); then, by reinforcement learning, an autonomous agent learns from its own experience. In view of this aim, the paper investigates the role of reward functions and different strategies to transfer experts' knowledge in various target task situations.

The last contributing in this special issue to Scientific Design is "Framework for metaphor-based spatial configuration design: a case study of Japanese rock gardens" by Kahlon and Fujii. The design of traditional Japanese rock gardens offers the opportunity to investigate the use of metaphors to guide the definition of layouts of elements in those design activities, where the visual impact has the most critical role. The normative approach to design here leverages the rules inherited from classical manuals for Japanese rock gardens design, and the authors claim that the proposed method is a first step toward integrating a metaphor-based conceptual design methodology into CAD environments; even transferrable to more general contexts of application and other fields.

Finally, the last set of papers deals with the Science of Design, that is, contributions that address Design as an object of study. Huang *et al*. in "Category, process and recommendation of design in an interactive evolutionary computation interior design experiment: a data-driven study" describe an experiment involving 230 subjects performing an interior design task supported by an Interactive Evolutionary Computation software. The data recorded in the design experiment are used for improving the interactive design system. This appears in line with the growing trend toward the collection and analysis of data in design tools as a means to enable behavioral characterization of users, in this case of designers, and also with the creation of novel training means.

Alternatively, design activities can be observed by recording and analyzing physiological data of subjects while designing. Borgiani and Maccioni in "Review of the use of neurophysiological and biometric measures in experimental design research" present an overview of the current studies exploiting those two specific measurement techniques. Despite still representing a niche in the design research domain, neurophysiological and biometric measures offer new means to investigate design cognitive constructs, tasks, and processes, beyond the limits of the traditional approaches of research. Scalability and objectivity, in fact, represent the main potential advantages with respect to experiments until now conducted in HBiD research.

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The last paper of the special issue is "Demonstration, extension and refinement of the re-proposed notion of design abduction" by Koskela and Kroll. The authors examine the invention of the airplane by the Wright brothers to extend their previous work on design abduction. Already considered a peculiar and essential cognitive process of creative design, abduction triggers several further types of inferences. The paper presents and discusses some of these types of inference by taking inspiration from the partial inventions that brought to the Wright brothers' invention.

Overall, as schematically represented in Table 1, the papers of the special issue span over all the different categories of research intent and approach depicted in Figure 1. This reflects the rich and multi-faceted articulation of the research on Design Computing and Cognition that exploits both empirical and normative approaches, as well as both virtual and real data. In other terms, despite being a very small sample of research contributions in this field, the special issue offers a plateau of contributions spanning from experimental studies to normative works stemming from formalized theories. Finally, the selected papers equally distribute between methodological developments aimed at improving design activities, applications of scientific approaches to design and studies on designing itself.

Reference

Cross N (2001) Designerly ways of knowing: design discipline versus design science. *Design Issues* **17**, 49–55.

Papers in the special issue. Borgianni Y and Maccioni L (2020) Review of the use of neurophysiological and biometric measures in experimental design research. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1–38. doi:10.1017/S0890060420000062.

Castro e Costa E, Jorge J, Knochel A and Duarte J (2020) Enabling parametric design space exploration by non-designers. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

Huang W, Su X, Wu M and Yang L (2020) Category, process and recommendation of design in an interactive evolutionary computation interior design experiment: a data-driven study. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

Kahlon Y and Fujii H (2020) Framework for metaphor-based spatial configuration design: a case study of Japanese rock gardens. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1–10. doi:10.1017/S0890060419000295.

Koskela L and Kroll E (2020) Demonstration, extension and refinement of the re-proposed notion of design abduction. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

Lester M, Guerrero M and Burge J (2020) Using evolutionary algorithms to select text features for mining design rationale. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1–15. doi:10.1017/S0890060420000037.

Liu X and Jin Y (2020) Reinforcement learning based collision avoidance: impact of reward function and knowledge transfer. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

Liu Y and Kaneda T (2020) Using agent-based simulation for public space design based on the Shanghai Bund waterfront crowd disaster. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1–15. doi:10.1017/S0890060420000049.

Mamoli M (2020) A shape grammar for the building-type definition of the ancient Greek and Roman library and the evaluation of library plans. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

Mars A, Grabska E, Slusarczyk G and Strug B (2020) Design characteristics and aesthetics in evolutionary design of architectural forms directed by fuzzy evaluation. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing.*

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Francesca Montagna Ph.D., is an associate professor at Politecnico di Torino where she teaches Management of Innovation and Product Development. She acquired a specialization in teaching methods at Harvard University and teaches also at MBA programs in Italy, as well as she actively collaborates in educational programs for managers, entrepreneurs, and policy-makers. Areas of expertise range from Management of Innovation, Engineering Design and Decision Making. Research activities are characterized by collaborations in projects at the national or international level (SMAT-F1, IPAS, PADGETS, OPENALPS, DEEP-INC). The themes are also deepened through innovation projects in the private and public sector (e.g., Alenia Aermacchi Spa, Thales Alenia Space, AVL List Gmbh, COMAU, P&G, Intesa Sanpaolo SpA, Azimut Yachts, Barilla SpA, Comune di Torino). Often, she is an expert evaluator of funding project proposals at the national and international level. She has authored or co-authored more than 60 academic papers and the book "Management of Innovation and Product Development: Integrating Business and Technological Perspectives". She is a member of Design Society and usually serves as a reviewer on international conferences and academic journals, such as Design Studies, RED, JED, AIEDAM, IJPR, and Computers in Industry.

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