

Will AI ever support Design Thinking?

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Abstract. This paper addresses the question of whether AI will ever support Design Thinking, with a focus on Architecture and Urban Planning, by analyzing the current trends of research in AI and related fields.

1 Introduction

Design was first considered as a “way of thinking” by Herbert A. Simon [34]. The notion was then applied in engineering design by Robert McKim [27] although a significant early usage of the term *Design Thinking* in the design research literature is due to Peter Rowe [32]. Rolf Faste expanded on McKim’s work at Stanford University in the 1980s and 1990s [14], teaching “design thinking as a method of creative action.” Design thinking was later adapted for business purposes by David M. Kelley, a Faste’s Stanford colleague, who founded IDEO¹ in 1991 and the Hasso Plattner Institute of Design at Stanford (aka d.school)² in 2004. The term has been popularized through several initiatives of the d.school.

Design Thinking is especially useful when tackling so-called *wicked problems*, *i.e.* problems that are ill-defined or tricky [6]. In wicked problems, both the problem and the solution are unknown at the outset of the problem-solving exercise. This is as opposed to *tame problems* where the problem is well-defined, and the solution is available through some technical knowledge. For wicked problems, the general thrust of the problem may be clear. However, considerable time and effort is spent in order to clarify the requirements. Therefore, a large part of the problem solving activity in Design Thinking consists of problem definition [32].

Whereas Problem Solving is at the core of AI research [24] and the interplay between AI and design research has been widely investigated [17], the question of whether machines can design still remains little addressed [11,13]. This paper addresses the question with a particular reference to Design Thinking in the realms of Architecture and Urban Planning.

The paper is structured as follows. Section 2 presents Design Thinking as a creative process for Problem Solving. Section 3 clarifies the difficulties of Design Thinking in Architecture and Urban Planning. Section 4 reports recent advances from the field of Computational Creativity which could affect AI research on Design Thinking. Section 5 outlines possible directions of AI research on Design Thinking in Architecture and Urban Planning. Section 6 concludes the paper with final remarks that reflect my position on the question in hand.

¹ <http://www.ideo.com/>

² <http://dschool.stanford.edu/>

2 Creative Problem Solving with Design Thinking

Principles. Christoph Meinel and Larry Leifer [28] assert that there are four rules to Design Thinking:

The human rule all design activity is ultimately social in nature

The ambiguity rule design thinkers must preserve ambiguity

The re-design rule all design is re-design

The tangibility rule making ideas tangible always facilitates communication

Suitable process models for Design Thinking should follow these principles.

Process. According to the Stanford's d.school, the Design Thinking process consists of the following 5 steps:

1. Understanding users' needs [EMPATHIZE].
2. Framing problems as opportunities for creative solutions [DEFINE].
3. Generating a range of possible solutions [IDEATE].
4. Communicating the core elements of solutions to others [PROTOTYPE].
5. Learning from users' feedback to improve solutions [TEST].

These steps are compliant with the aforementioned rules.

At the core of this process is a bias towards *action* and *creation* which, if repeated iteratively, allow the design thinker to refine his/her initial ideas until they are considered satisfactory from the point of view of the intended users. Also, because of Design Thinking's parallel nature, there are many different paths through the phases. This is part of the reason Design Thinking may seem to be "ambiguous" when compared to more analytical, Cartesian methods of science and engineering. Design thinkers also use *divergent thinking* and *convergent thinking* to explore many possible solutions [12]. Divergent thinking is the ability to offer different, unique or variant ideas adherent to one theme while convergent thinking is the ability to find the "correct" solution to the given problem. Design thinking encourages divergent thinking to ideate many solutions (possible or impossible) and then uses convergent thinking to prefer and realize the best resolution. The "a-ha moment" is the moment where there is suddenly a clear forward path. It is the point in the cycle where synthesis and divergent thinking, analysis and convergent thinking, and the nature of the problem all come together and an appropriate resolution has been captured.

Methods. Although design is always influenced by individual preferences, Design Thinking methods share a common set of traits, mainly: *creativity*, ambidextrous thinking, teamwork, empathy, curiosity and optimism [14]. Methods include interviewing, defining user profiles, looking at other existing solutions, developing prototypes, mind mapping, asking questions like the five whys and situational analysis. Higher-order and obscure relationships, typically occurring in wicked problems, are usually addressed through the use of *analogies* [19]. An understanding of the ill-defined elements of the situation, or the expected results, or lack of domain-related knowledge for the task, may be developed by correlating different internal representations, such as *images* [27].

3 Design Thinking in Architecture and Urban Planning

Design Thinking has been deeply investigated in Architecture and Urban Planning since early 1970s. In particular, the work of psychologist, architect and design researcher Bryan Lawson has contributed to the understanding of the distinguishing features of Design Thinking with respect to other forms of Problem Solving [21]. The fame of Lawson arises from an empirical study conducted in 1972 to investigate the difference between *problem-focused* solvers and *solution-focused* solvers. He took two groups of students (final year students in architecture and post-graduate science students) and asked them to create one-layer structures from a set of colored blocks so that the perimeter of the structure had to optimize either the red or the blue color. However, there were unspecified rules governing the placement and relationship of some of the blocks (incomplete problem statement). By observing the solution approaches adopted by the two groups, Lawson found that the scientists are problem-focused solvers whereas designers are solution-focused solvers [21]. In 1973 Horst Rittel and Melvin Webber showed that design and planning problems are wicked problems as opposed to tame problems of science [31]. Later on, Nigel Cross concluded that Lawson's studies suggest that scientists problem solve by *analysis*, while designers problem solve by *synthesis* [9]. Actually, Design Thinking uses both analysis and synthesis. Every synthesis is built upon the results of a preceding analysis, and every analysis requires a subsequent synthesis in order to verify and correct its results. Pieter Pauwels, Ronald De Meyer, and Jan Van Campenhout [30] suggest that creative Design Thinking in Architecture rests on a cyclic combination of reasoning processes based on *abduction*, *deduction*, and *induction*.

Methods and approaches used by architects and urban planners were extensively described by Peter Rowe in his 1987 book on Design Thinking [32]. In recent years, as a consequence of a number of dramatic scientific discoveries (notably, the notion of *embodiment* from *neurosciences*), traditional arguments such as "nature versus nurture" [10] are rapidly disappearing because of the realization that just as we are affecting our environments, so too do these altered environments restructure our cognitive abilities and outlooks. If the biological and technological breakthroughs are promising benefits such as extended life expectancies, these same discoveries also have the potential to improve in significant ways the quality of our built environments. This poses a compelling challenge to conventional architectural theory. Drawing upon a wealth of research, Harry F. Mallgrave [26] argues that architects should turn their focus away from the objectification of architecture (*i.e.*, treating architectural design as the creation of objects) and redirect it back to those for whom they design: the people inhabiting their built environments. Mallgrave is the first to consider the "human rule" (see Section 2) in architectural terms and to question what implications the discussions taking place in philosophy, psychology, biology, anthropology, and neurosciences hold for architectural design.

In architectural design, *creativity* is highly valued. Although several methods for stimulating creativity are available in the literature, they are rarely formally present in the architectural design process. Also, the assessment of creativity is

an open issue, mainly due to the lack of an unambiguous disciplinary definition of creativity. However, some progress has been done as shown in the next section.

4 Advances from Computational Creativity Research

Creativity is a phenomenon typically characterized in terms of its product. In particular, it results in products that are (i) novel, (ii) useful or valuable, and (iii) non-obvious, unexpected or surprising. *Computational Creativity* (CC) concerns the use of computers to generate results that would be regarded as creative if performed by humans alone. More precisely, the goal of CC is to model, simulate or replicate creativity using a computer, to achieve one of several objectives:

- To construct a program or computer capable of human-level creativity.
- To better understand human creativity and to formulate an algorithmic perspective on creative behavior in humans.
- To design programs that can enhance human creativity without necessarily being creative themselves.

A prophecy of the advent of CC can be traced back to over 170 years ago, when Ada Lovelace said of Charles Babbage’s Analytical Engine that it “might compose elaborate and scientific pieces of music of any degree of complexity or extent” [29]. However, CC includes not only the arts, but also, *e.g.*, innovative scientific theories and engineering design.

Creativity was identified as one of the primary goals of AI in the Dartmouth proposal. However, the pioneers of AI ignored the CC challenges because they were interested in modeling mental processes rather than building useful tools. The interest of the AI community in creative machines is now increasing [1]. Simon Colton, Ramon Lopez de Mantaras and Oliviero Stock [7] provide a review of more recent developments in AI research on CC. These developments build partially on psychological studies, socio-psychological studies, socio-cultural studies and philosophical analysis of creativity. In particular, the work of Margaret Boden has been highly influential [3,4]. Boden’s insights have guided work in CC at a very general level, providing more an inspirational touchstone for development work than a technical framework of algorithmic substance. However, notions such as *exploratory creativity* have been more recently formalized and operationalized, most notably in Geraint Wiggins’ framework for description, analysis and comparison of creative systems [35].

Colton and Wiggins [8] have called CC the “final frontier” for AI research. However, fundamental research should be done to make AI able to face the challenges of CC. Selmer Bringsjord, Paul Bello, and David A. Ferrucci [5] have already pointed out the inadequacy of the Turing Test in the case of creative machines. A better test is one that insists on a certain restrictive epistemic relation between an artificial agent (or system) A , its output o , and the human architect H of A – a relation which, roughly speaking, obtains when H cannot account for how A produced o . This test was called the *Lovelace Test* in honor of Ada Lovelace, who believed that only when computers originate things should they be believed to have minds.

5 Directions of AI Research on Design Thinking

In this Section I mention increasingly challenging directions for AI research on Design Thinking in Architecture and Urban Planning.

Developing intelligent Geographical Information Systems (GIS) and Computer-Aided Design (CAD) systems. An early work on AI in Urban Planning is INGENS, a prototypical GIS which integrates *machine learning* tools to assist planners in the task of topographic map interpretation [25]. It can be trained to learn operational definitions of geographical objects that are not explicitly modeled in the database. Carl Schultz and Mehul Bhatt [33] present a multimodal spatial data access framework designed to serve the informational and computational requirements of CAD systems that are intended to provide intelligent spatial *decision support* and analytical capabilities in Architecture. Bhatt *et al.* [2] interpret (structural) form and (artefactual) function by specifying modular *ontologies* and their interplay for the Architectural Design domain. They also demonstrate how their ontological modelling facilitates the conceptual modelling of requirement constraints in Architectural Design.

Pushing the “human rule”. As mentioned in Section 3, Mallgrave promotes a *user-centered design* approach in Architecture. But how to make AI systems for Design Thinking compliant with the “human rule”? This can be achieved by applying AI techniques for *sentiment analysis*, *opinion mining* and *preference learning*. A recent attempt in this direction is the proposal of an approach to rank buildings through the automated analysis of Flickr metadata on the Web with the aim of measuring the public perception of particular building types (airports, bridges, churches, halls, and skyscrapers) [16]. Learning from user preferences is also central in a very recent AI application to a problem relevant in Urban Planning, *i.e.* the definition of an integrated touristic plan for urban areas [23].

Towards creative systems. The pioneer of CC in Architecture was John Frazer, whose work - as a student - on CAD and “intelligent environments won an Architectural Association prize as early as 1969. With his wife Julia Frazer, he went on to provide more elaborate computer-generated (and eventually interactively evolved) designs for buildings and urban centres [15]. He investigates the fundamental form-generating processes in Architecture, considering architecture as a form of artificial life, and proposing a genetic representation in a form of DNA-like code-script, which can then be subject to developmental and evolutionary processes in response to the user and the environment. After Frazer, other researchers have taken inspiration from nature in order to enhance CAD systems with some creative capabilities [18]. Creative CAD systems are intended to go beyond the abovementioned intelligent CAD systems since they aim at *machine creativity* rather than at *machine-supported human creativity* [22]. Ashok Goel *et al.* [20] envision that the next generation of knowledge-based CAD systems will be based on cognitive accounts of design, and will support collaborative design, conceptual design, and creative design.

6 Final remarks

In this paper I have addressed the question of whether machines can design. This capability is intertwined with the ability to autonomously pursue a Design Thinking process, *e.g.*, the one suggested by the d.school and briefly described in Section 2. So, the original question can be reformulated as to whether AI will ever support Design Thinking, meaning both the process and all the reasoning tasks involved in the process. Available AI techniques - notably those developed in the areas of sentiment analysis, opinion mining and preference learning as mentioned in Section 5 - can support the steps [EMPATHIZE] and [DEFINE] in the process. As for the last two steps in the Design Thinking process (*i.e.*, [PROTOTYPE] and [TEST]), rapid prototyping is now possible with 3D-printing technologies which have been developing at an amazing pace. Neri Oxman, architect and founder of the Mediated Matter group at the MIT Media Lab,³ argues that *digital fabrication* is ushering in a third era of construction technology. There are still many limitations, such as the range of materials you can use, the maximum size you can print at and the speed of the process. However, as testified by the pioneering work of engineer Enrico Dini with his architectural-scale 3D-printer *D-Shape*,⁴ in the near future we might print not only buildings, but entire urban sections. So, the communication of the design solutions to the users will become easier and faster than it is nowadays. Last but not least, in order to fulfill the requirements of a machine capable of Design Thinking, it is necessary to cover also the central step of the process, namely [IDEATE]. This implies that one such machine, besides being intelligent, should be also creative.

Current research in AI testifies a great effort towards the development of creative machines. So, as opposed to Pauwels *et al.* [30], I am not skeptical about the possibility that AI could support Design Thinking, even in challenging domains such as Architecture and Urban Planning. Good news come also from the field of CC. According to Boden [4], high levels of creativity result from the transformation of a conceptual space. In [35], Wiggins mentioned that Boden's *transformational creativity* could be achieved computationally by extending his framework so that search could range over the possible traversal and evaluation functions, as well as the conceptual spaces defined by each such choice. Such an extension would correspond to instatiating the design processes, more precisely the phases of divergent thinking. So it is very likely that next-generation AI systems will include more and more of the processes peculiar to Design Thinking, resulting also in an augmented perception of their creativity.

Summing up, I am enclined to think that creative machines for Design Thinking in Architecture and Urban Planning could be obtained by equipping upcoming mega-scale 3D-printers with software that combines the facilities of a CAD system with the automated inferences of AI-based reasoning engines and the generative capabilities of CC tools.

³ <https://www.media.mit.edu/people/neri>

⁴ <http://www.d-shape.com/index.htm>

References

1. Besold, T.R., Schorlemmer, M., Smaill, D. (eds.): Computational Creativity Research: Towards Creative Machines, Atlantis Thinking Machines, vol. 7. Springer (2015)
2. Bhatt, M., Hois, J., Kutz, O.: Ontological modelling of form and function for architectural design. *Applied Ontology* 7(3), 233–267 (2012), <http://dx.doi.org/10.3233/A0-2012-0104>
3. Boden, M.A.: Creativity and artificial intelligence. *Artificial Intelligence* 103(1-2), 347–356 (1998), [http://dx.doi.org/10.1016/S0004-3702\(98\)00055-1](http://dx.doi.org/10.1016/S0004-3702(98)00055-1)
4. Boden, M.A.: *The Creative Mind - Myths and Mechanisms* (2. ed.). Routledge (2003)
5. Bringsjord, S., Bello, P., Ferrucci, D.A.: Creativity, the Turing Test, and the (better) Lovelace Test. *Minds and Machines* 11(1), 3–27 (2001), <http://dx.doi.org/10.1023/A:1011206622741>
6. Buchanan, R.: Wicked problems in design thinking. *Design Issues* 8(2), 5–21 (1992)
7. Colton, S., López de Mántaras, R., Stock, O.: Computational creativity: Coming of age. *AI Magazine* 30(3), 11–14 (2009), <http://www.aaai.org/ojs/index.php/aimagazine/article/view/2257>
8. Colton, S., Wiggins, G.A.: Computational creativity: The final frontier? In: De Raedt, L., Bessière, C., Dubois, D., Doherty, P., Frasconi, P., Heintz, F., Lucas, P.J.F. (eds.) *ECAI 2012 - 20th European Conference on Artificial Intelligence. Including Prestigious Applications of Artificial Intelligence (PAIS-2012) System Demonstrations Track*, Montpellier, France, August 27-31, 2012. *Frontiers in Artificial Intelligence and Applications*, vol. 242, pp. 21–26. IOS Press (2012), <http://dx.doi.org/10.3233/978-1-61499-098-7-21>
9. Cross, N.: Designerly ways of knowing. *Design Studies* 3(4), 221–227 (1982)
10. Cross, N.: The nature and nurture of design ability. *Design Studies* 11(3), 127–140 (1990)
11. Cross, N.: Can a machine design? *Design Issues* 17(4), 44–50 (2001)
12. Cross, N.: *Designerly Ways of Knowing*. Springer (2006)
13. Cross, N.: *Design Thinking: Understanding How Designers Think and Work*. Oxford: Berg Publishers (2011)
14. Faste, R.A.: Ambidextrous thinking. In: *Innovations in Mechanical Engineering Curricula for the 1990s*. American Society of Mechanical Engineers (1994)
15. Frazer, J.H.: *An Evolutionary Architecture*. Architectural Association: London (1995)
16. Gadiraju, U., Dietze, S., Diaz-Aviles, E.: Ranking buildings and mining the web for popular architectural patterns. In: *Proceedings of the ACM Web Science conference*, Oxford, UK, June 28 - July 1, 2015. (2015)
17. Gero, J.S.: AI EDAM at 20: Artificial intelligence in designing. *AI EDAM* 21(1), 17–18 (2007), <http://dx.doi.org/10.1017/S0890060407070084>
18. Goel, A.K.: Design, analogy, and creativity. *IEEE Expert* 12(3), 62–70 (1997)
19. Goel, A.K., Shu, L.H.: Analogical thinking: An introduction in the context of design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 29(2), 133–134 (2015), <http://dx.doi.org/10.1017/S0890060415000013>
20. Goel, A.K., Vattam, S., Wiltgen, B., Helms, M.E.: Cognitive, collaborative, conceptual and creative - four characteristics of the next generation of knowledge-based CAD systems: A study in biologically inspired design. *Computer-Aided Design* 44(10), 879–900 (2012), <http://dx.doi.org/10.1016/j.cad.2011.03.010>

21. Lawson, B.R.: *How Designers Think: The Design Process Demystified*. Architectural Press, Oxford (1980)
22. Lawson, B.R.: CAD and creativity: does the computer really help? *Leonardo* 35(3), 327–331 (2002)
23. Lisi, F.A., Esposito, F.: An AI application to integrated tourism planning. In: Gavanelli, M., Lamma, E., Riguzzi, F. (eds.) *AI*IA 2015, Advances in Artificial Intelligence - XIVth International Conference of the Italian Association for Artificial Intelligence*, Ferrara, Italy, September 23–25, 2015, *Proceedings. Lecture Notes in Computer Science*, vol. 9336, pp. 246–259. Springer (2015), http://dx.doi.org/10.1007/978-3-319-24309-2_19
24. Luger, G., Stubblefield, W.: *Artificial Intelligence: Structures and Strategies for Complex Problem Solving*. Benjamin/Cummings (2004)
25. Malerba, D., Esposito, F., Lanza, A., Lisi, F.A., Appice, A.: Empowering a GIS with inductive learning capabilities: the case of INGENS. *Computers, Environment and Urban Systems* 27(3), 265–281 (2003)
26. Mallgrave, H.F.: *Architecture and Embodiment: The Implications of the New Sciences and Humanities for Design*. Routledge (2013)
27. McKim, R.: *Experiences in Visual Thinking*. Brooks/Cole Publishing Co. (1973)
28. Meinel, C., Leifer, L.: Introduction. In: Leifer, L., Plattner, H., Meinel, C. (eds.) *Design Thinking Research - Building Innovation Eco-Systems*. Springer (2014)
29. Menabrea, L.F.: Sketch of the Analytical Engine invented by Charles Babbage. *Scientific Memoirs* 3 (1843)
30. Pauwels, P., De Meyer, R., Van Campenhout, J.: Design thinking support: Information systems versus reasoning. *Design Issues* 29(2), 42–59 (2013)
31. Rittel, H.W., Webber, M.M.: Dilemmas in a general theory of planning. *Policy Sciences* 4(2), 155–169 (1973), <http://dx.doi.org/10.1007/BF01405730>
32. Rowe, G.P.: *Design Thinking*. The MIT Press (1987)
33. Schultz, C.P.L., Bhatt, M.: Multimodal spatial data access for architecture design assistance. *AI EDAM* 26(2), 177–203 (2012), <http://dx.doi.org/10.1017/S0890060412000066>
34. Simon, H.: *The Sciences of the Artificial*. The MIT Press (1969)
35. Wiggins, G.A.: A preliminary framework for description, analysis and comparison of creative systems. *Knowledge-Based Systems* 19(7), 449–458 (2006), <http://dx.doi.org/10.1016/j.knosys.2006.04.009>