The Fifth International Conference on Design Creativity (ICDC2018)
Bath, UK, January 31st – February 2nd 2018

THEORETICALLY COMPARING DESIGN THINKING TO DESIGN METHODS FOR LARGE-SCALE INFRASTRUCTURE SYSTEMS

M.A. Guerra[1] and T. Shealy[1]

[1]Civil Engineering, Virginia Tech, Blacksburg, USA

Abstract: Design of new and re-design of existing infrastructure systems will require creative ways of thinking in order to meet increasingly high demand for services. Both the theory and practice of design thinking helps to exploit opposing ideas for creativity, and also provides an approach to balance stakeholder needs, technical feasibility, and resource constraints. This study compares the intent and function of five current design strategies for infrastructure with the theory and practice of design thinking. The evidence suggests the function and purpose of the later phases of design thinking, prototyping and testing, are missing from current design strategies for infrastructure. This is a critical oversight in design because designers gain much needed information about the performance of the system amid user behaviour. Those who design infrastructure need to explore new ways to incorporate feedback mechanisms gained from prototyping and testing. The use of physical prototypes for infrastructure may not be feasible due to scale and complexity. Future research should explore the use of prototyping and testing, in particular, how virtual prototypes could substitute the experience of real world installments and how this influences design cognition among designers and stakeholders.

Keywords: *Design thinking, design of infrastructure systems*

1. Introduction

Infrastructure systems account for the vast majority of energy use and associated carbon emissions in the United States (US EPA, 2014). Unfortunately, emissions from these infrastructure systems continue to increase annually (US EPA, 2016). At the same time, service capacity continues to decline. For example, the U.S. electricity grid loses more power today than in the 1980's (Hobbs & Kameshwar, 2013; Hoffman & Bryan, 2012) costing businesses on average $150 million annually (Department of Energy, 2014) and traffic fatalities rose in 2015, ending a 5-decade decline (Henry, 2016). The purpose of this study is to help those responsible for solving these complex infrastructure problems develop new and creative ways of thinking.

Innovative thinking comes from the ability to exploit opposing ideas and constraints (Johansson-Sköldberg et al., 2013). The theory of design thinking builds innovative solutions not only by exploiting opposing ideas by also balancing stakeholder needs, technical feasibility, and resource constraints (Brown & Wyatt, 2010). Navigating these dimensions requires iterations of perspective taking, problem scoping, ideation, and testing (Dix, 2009; Vredenburg et al., 2002). There are numerous prescriptive methods and approaches in design literature that help designers fluently manoeuvre among these dimensions and constraints (Brown, 2008; Buchanan, 1992; Cross et al., 1992; Faste, 1994).

One approach is the design thinking process develop by Hasso Platner (2006), which is well established both within design literature (Plattner et al., 2010; Vredenburg et al., 2002) and in practice (Plattner et al., 2010). It is effectively applied in health services (Joosten et al., 2009; Kimbell, 2011; Kumar et al., 2009), software design (Burdick & Willis, 2011; Murty et al., 2010), and business (Davis, 2010; Glen et al., 2014). For example, design thinking methodology has led to new procedures and software that radically streamlined information exchange in hospitals, creating better-informed patient care (Brown, 2008).

The paper begins by detailing the theory behind design thinking and presenting the five-step process developed by Hasso Platner (2006). The methods section then outlines how current industry strategies in design of infrastructure were chosen to compare to design thinking. The results and discussion highlight current gaps in design strategies for infrastructure and the conclusion makes recommendations to adopt an approach that better incorporates the dimensionality and iterative process that comes from design thinking.

2. Backgrounds

Design thinking can be traced to the 1950's and 1960's, but it was not formally used until 1987 when it appeared in Peter Rowe's book Design Thinking (Rowe, 1987, 1991). Rowe defines design thinking as a holistic approach where the problem is at the center of the solution production process, instead of the traditional viewpoint that the design process shapes the solution. A more recent definition by Martin (2009) refers to design thinking as integrative thinking, the ability to confront opposing constraints to create new innovative solutions. Although the term design thinking continues to evolve, what remains consistent is that design thinking takes designers through inspiration, ideation, and implementation to deliver design solutions that are user centered.

The five step process proposed by Hasso Platner (2006) operationalizes design thinking, providing a prescriptive process. The five-step process moves through from empathizing to defining, ideating, prototyping, and testing. Through empathizing and defining the designer can begin by understanding what users really want and need in order to develop an accurate problem statement. Ideation promotes generating as many ideas as possible. Only after ideas are generated are they balanced with the design constraints. Prototyping and testing generate user data to inform the process. This phase, in particular, is an iterative process (Burnett, 2016).

Many fields have applied Hasso Platner's design thinking process with successful results. It has rapidly grown into other fields such as information technology (Dorst, 2011; Lindberg et al., 2011), manufacturing (Cooper et al., 2009; Leong & Clark, 2003; Qi, 2009), and education (Dunne & Martin, 2006; Goldschmidt, 1994; Oxman, 2004). Below, the theory behind each of the steps are detailed, in effort, to provide and illustrate the value they provide to the design process. In the methods and results section these steps are then compared to existing design strategies for infrastructure.

The first step within design thinking is empathize. Empathy is the ability to accurately perceive what someone else is feeling or experiencing (Gasparini, 2015; Kouprie & Visser, 2009). Empathizing with the end users brings meaningful information into the early stages of design (Gasparini, 2015). The process of empathy in design can be broken into four stages: discovery of the users' world, immersion in the users' world with the user as the point of reference, the emotional connection with the experience, and finally, the detachment from the users' world into the designer's own perspective (Kouprie & Visser, 2009). In design thinking, empathy is the first step because it allows the designers to understand the culture and context where the problem originates, which helps to reduce the biases and preconceptions designers may have in order to place their perspective in the current world.

The second step is to clearly define the problem statement. Designers synthesize the needs and insights they obtained from the previous step and develop an inventory of users' needs and desires (Kembel, 2009). The previous step of empathizing helps to create a state of mind and brings new knowledge into the process of defining the problem. Defining the problem is the step that directs the subsequent efforts of the designers to solve the underlying root issues (Gestwicki & McNely, 2012).

The third step in the five-step design thinking process is to ideate possible solutions. The accuracy on the previous two steps, empathize and define, is essential for the success of ideation because here is where designers generate solutions to address the problem defined before. In ideation, designers are encouraged to bring as many ideas as possible, without considering if the solutions are feasible. The goal is to cross the limits of traditional design (Kembel, 2009). With all the ideas on the table, designers should proceed to balance them among the multiple dimensions and constraints of user desirability, technical feasibility, and resource constraints. There are many techniques to develop creative ideation (Goldenberg et al., 1999; Jonson, 2005) and also to measure the effectiveness (Shah et al., 2003) of the ideation processes. Design thinking is an iterative process in which ideation is the first step where more promising ideas for solutions are selected, built, and then tested.

Prototyping the selected solutions is a central activity for innovative and creative design, allowing designers to build hypothesized solutions. Prototyping helps frame the problem into a thinking-by-doing methodology (Hartmann et al., 2006). The feedback obtained from users when they are testing a product or service is much richer because users can see what the future looks like, which improves the quality of data to feed the design. Prototyping in design thinking also reduces the fear of failure on designers because they build the potential solutions early in order to get information. David Kelly (2006) defines this step as failure immunity because designers see prototyping success or failure as a mechanism to enrich the design process. The potential solution is then put to the users for them to test. This stage gathers feedback about how well the prototype meets the needs of the end user (Razzouk & Shute, 2012). The solution provided to the users is finalized in this step. However, design thinking is an iterative process, which means that if the result of the solution is not satisfactory, the process does not end but goes back to one of the previous phases, repeating each step as many times as necessary (Dym et al., 2005).

This five-step design thinking process helps designers overcome the "fear of failure" because the understanding of the real users' issues elicited from the empathize and define steps allows designers to build ideas on a solid foundation (Kelley & Kelley, 2006). Designers are encouraged to ideate without thinking about limits and to use prototyping and testing as a feedback loop to continue improving the design. While none of these steps individually are revolutionary, the prescriptive design thinking process is accessible, allowing non-traditional or trained designers an approach to follow.

The accessibility of the process is why this approach was used to compare to current processes used in design of infrastructure systems. In this study, we use current infrastructure design strategies that are well defined from literature. The design strategies include stakeholder management, community participation, charrette, lean design and construction, and value sensitive design. In the remainder of this section, each of these design strategies is defined in more detail and compared to the functional steps within the design thinking process.

3. Research Objective and Methodology

The objective of this study is to compare the intent and function of current design strategies for infrastructure with design thinking practices. Five currently used design strategies were critically reviewed. Similarities and gaps in intent and function between infrastructure design strategies and design thinking are highlighted. Some of the design strategies for infrastructure are better established, such as the charrette process, while others are still emerging, such as value sensitive design. The origins of these design processes, the principles that govern them, and how they are applied were categorized along each step of design thinking. This comparison is meant to overlay current practices and illustrate opportunity for improvement during the design of infrastructure.

4. Results and Discussion

The design strategies that were compared to design thinking include stakeholder management, community participation, charrette design, lean design and construction, and value sensitive design. None of these five design strategies for infrastructure integrate all of the intended outcomes from the design thinking steps. When these design strategies are compared to design thinking, they are predominantly front loaded. Meaning, four out of the five strategies incorporate aspects of empathizing and perspective taking and intentionally spend time to develop the problem statement.

The majority do provide opportunity for ideation. However, none include a formalized feedback mechanism that includes prototyping. Figure 1, illustrates this review of design strategies. In the following subsections, each design strategy is further explained and more detail about the intent and functional purpose are included and compared to design thinking.

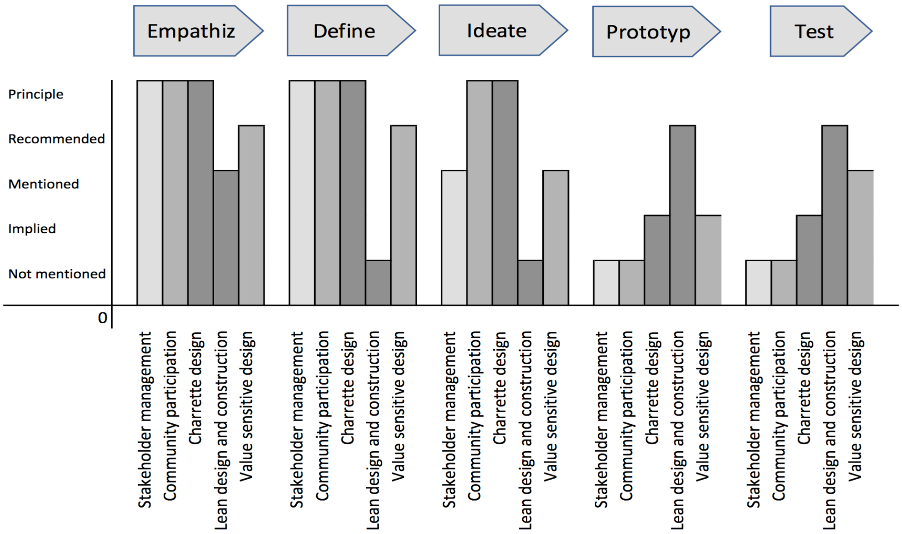

Fig. 1. Functional similarities between design strategies used for infrastructure systems and Hasso Plater's (2006) design thinking process

4.1. Stakeholder Management

Stakeholder management and design thinking share important similarities in their design processes. Within literature about infrastructure, stakeholder management does not only mean searching to understand what is important for the end-user but searches for a wider spectrum of all the stakeholders who are involved in the project. In this wider spectrum, the end users' input is just one out of all the other stakeholders' inputs. As a consequence of this broader spectrum of sources, designers define the problem, balancing the feedback from all stakeholders. These multiple perspectives is meant to remove the risk of overlooking root problems (Osman et al., 2007). However, it can also lead to overlooking key user groups. Designers need to be conscious of when to use the acquired information, making an explicit effort to empathize with the end-users and to include the end-users' feedback in the design phase. The process of balancing ideas for solutions between the constraints presented by the stakeholders is a slight attempt to obtain feedback from stakeholders, which prototyping and testing do in design thinking processes.

4.2. Community Participation

Community participation is a sub-task within stakeholder management; however, because of the large amount of literature and applications (Berman et al., 1999), it is often studied independently. Comparing community participation with design thinking, the empathize and define stages of design thinking are exemplified by community participation. There is a conscious effort for designers to feel what the end-user is experiencing, such that the designer can identify the roots from which the problem originates. Second, ideation is also a trait in community participation, although it is not as explicit as design thinking intends. Involving the community to also participate in the ideation process brings solutions from multiple points of view; it is not about validating a proposed solution but about validating that designers are asking the appropriate questions. This exercise allows ideas which may not be common for one field to be put on the table by someone with another perspective. Similar to stakeholder engagement, community participation does not propose provide or attempt to include feedback through prototyping or testing exercises. In other words, community participation used within infrastructure design is front loaded among the steps within design thinking.

4.3. Charrette

A charrette is a collaborative design method that aims to deliver a project with the support of all stakeholders, while also significantly reducing the design delivery time (Lennertz & Lutzenhiser, 2014). The Charrette design process shares principles with early steps of design thinking. The first design thinking step, empathy, is closely aligned with the Charrette design method, requiring a site visit such that designers gain a sense of the culture and the community for which they are designing. The location where the charrette occurs is also recommended to serve as the design site itself (Lennertz & Lutzenhiser, 2014). It brings as many stakeholders' opinions and feedback as possible and it is in constant interaction with the community. Designers are encouraged to hold pre-charrette visits and meetings, in effort, to lead toward identifying the root problem, which is the second step of design thinking. Also, the constant feedback from the community and the stakeholders in general keeps the design team from designing away from the underlying, root problem. The Charrette process shares similar characteristics with the third design thinking step, ideation. The constant feedback from the community suggestions bring new ideas to the design table (Brown & Wyatt, 2010).
While the Charrette process holds similar functions as empathize, define, and ideate in design thinking, it falls short in prototyping and testing. To counteract this omission, the Charrette process requires at least three feedback loops, which helps designers reduce their perceived risks, feeling that they can fail twice as a function of the process. The Charrette process also does not have a step to test the design along user behaviours or intended use. This is perhaps one of the big pitfalls of this strategy; not all projects that use the charrette process get built (Lennertz, 2016). In design thinking, testing helps clear the potential barriers to implement and adopt the design. Overall, the Charrette process has strong traits that do function similarly at the the first three steps within design thinking, yet, similar to the previous methods, falls short to provide adequate prototyping and testing of design being used by the intended users.

4.4. Lean Design and Construction

In lean design and construction, designers and builders try to minimize the waste of resources—time, money, materials—through a design process coordinating flow, conversion, and value characteristics (Freire & Alarcón, 2002). One example is the application of prefabricated features to reduce construction waste (Tam & Hao, 2014). Lean design and construction shifts the stakeholders and users out of focus, bringing the delivery process to the center. Construction-led design does not involve empathizing with the end-user, nor, as a consequence, defining the roots of the problem. In many instances, lean design and construction techniques should be used in combination with other methods and techniques. Here, designers focus on a set of project requirements without much consideration for end-users. However, there is a form of the ideation similar to design thinking. The process of ideation occurs when designers balance the ideas among the innovation constraints of technical feasibility, economic viability, and specific project requirements. An important restriction to note is that the technology feasibility is intended to mean within the construction process.
Lean design and construction provide opportunities for prototyping and testing. Construction-led designers and engineers are encouraged to design artefacts, features, and processes that have already been tested and that work for the intended purpose. Features and processes include prefabricated and modular design, which can be prototyped and tested off-site, with better equipped locations and testing facilities, improving the quality and reducing the risk of on-site work. Unlike the previous methods described, lean design and construction do emphasize prototyping and testing in the design process. Those who adopt this method recognize the value gained in the ability to test and innovative (Chen & Taylor, 2009). Often this is described as an impetus to innovation, especially in construction (Al-Sudairi, 2007; Ozorhon, 2012; Segerstedt et al., 2010).

4.5. Value Sensitive Design

Value Sensitive Design (VSD) is an integrative and iterative process that aims to understand values and preferences of both the direct and indirect stakeholders (Friedman et al., 2002). VSD mirrors the first steps of design thinking. VSD's process of investigation is dedicated to understanding the direct and indirect stakeholders, empathizing with them and learning which values are transcendental (Le Dantec et al., 2009). This strong process of empathizing leads the designers to identify roots of the problems and helps them define the problem accurately. VSD then puts together the users' requirements and the technical feasibility through ideation (Friedman et al., 2002). VSD does not explicitly state a prototyping or testing phase or mechanism to gain user feedback. Although VSD has been used in design and information technology—fields in which testing prototypes is a common step—however this may not be the case in other fields (van der Hoven & Manders-Huits, 2009).

5. Conclusion

The current infrastructure design strategies include functional similarities to the steps within Hasso Platner's (2006) design thinking. Although, the formal strategies applied to design of infrastructure appear front-loaded, emphasizing perspective taking, empathy, problem identification, and ideation over prototyping and testing. To compensate for this lack of feedback, stakeholder management attempts to obtain feedback from stakeholders, and designers early in the process but fails to provide checks or revaluation later. Community participation engages stakeholders throughout the ideation phase. The community is encouraged to propose their own solutions frequently. Feedback is emphasized later in the design process but community participation fails to receive the rich feedback provided through user observation and testing. The Charrette design process is more comprehensive, integrating functional aspects of stakeholder management and community participation through three structured feedback stages. These three stages hold a similar intent to prototyping and testing where fear of failure is removed from ideation and testing. Lean design and construction replaces downstream users with project constraints as the center of the process. Those who adopt a lean approach value the ability to test and prototype in effort to develop more efficient processes and products. Value sensitive design is an iterative process that provides feedback from users but does not do so through observations or testing of prototypes. The evidence suggests the functionality and purpose of the later phases of design thinking, to gain increasing feedback from user observations is missing. This is a critical stage where designers learn information about the project performance and its interaction with the users' context and culture through built projects.

Those designing infrastructure need to explore new ways to incorporate feedback from users because without closing the feedback loop, infrastructure designers are missing critical information to inform design. Although, physical prototypes may not be feasible for every infrastructure design due to economic or resource constraints. So, virtual prototyping may provide a solution. This includes degrees of virtual reality from 2D, 3D and immersive experiences. More research is need to measure whether and how virtual prototypes can substitute the experience of real world installments and how this influences design cognition among infrastructure stakeholders.

While design theories certainly apply to design of infrastructure many methods were not created with this scale and complexity in mind. The current methods for design of infrastructure appear inadequate when compared to design thinking. Future research in design can help bridge this gap by developing new and testing existing engineering design methods for large-scale infrastructure systems. More specifically, research is needed in formalizing a feedback mechanism for infrastructure design that includes observing user behaviour during interaction with the proposed solution.

References

Al-Sudairi, A. A. (2007). Evaluating the effect of construction process characteristics to the applicability of lean principles. *Construction Innovation*, *7*(1), 99–121.

Berman, S. L., Wicks, A. C., Kotha, S., & Jones, T. M. (1999). Does stakeholder orientation matter? The relationship between stakeholder management models and firm financial performance. *Academy of Management Journal*, *42*(5), 488–506.

Brown, T. (2008). Design thinking. *Harvard Business Review*, *86*(6), 84.

Brown, T., & Wyatt, J. (2010). Design thinking for social innovation. *Development Outreach*, *12*(1), 29–43.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, *8*(2), 5–21.

Burdick, A., & Willis, H. (2011). Digital learning, digital scholarship and design thinking. *Design Studies*, *32*(6), 546–556.

Burnett, B. (2016, April). *Design Thinking = Method, Not Magic*. Stanford University. Retrieved from https://www.youtube.com/watch?v=vSuK2C89yjA

Chen, H., & Taylor, R. (2009). Exploring the impact of lean management on innovation capability. In *Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference on* (pp. 826–834). IEEE.

Cooper, R., Junginger, S., & Lockwood, T. (2009). Design thinking and design management: A research and practice perspective. *Design Management Review*, *20*(2), 46–55.

Cross, N., Dorst, K., & Roozenburg, N. (1992). Research in design thinking. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid%3A83a0d981-d053-4944-90af-3d165b9d079e

Davis, B. M. (2010). Creativity & innovation in business 2010 teaching the application of design thinking to business. *Procedia-Social and Behavioral Sciences*, *2*(4), 6532–6538.

Department of Energy. (2014). *The Sart Grid: An Introduction* (The Smart Grid No. No. DE-AC26-04NT41817). Retrieved from https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages%281%29.pdf

Dix, A. (2009). Human-computer interaction. In *Encyclopedia of database systems* (pp. 1327–1331). Springer.

Dorst, K. (2011). The core of "design thinking"and its application. *Design Studies*, *32*(6), 521–532.

Dunne, D., & Martin, R. (2006). Design thinking and how it will change management education: An interview and discussion. *Academy of Management Learning & Education*, *5*(4), 512–523.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, *94*(1), 103–120. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

Faste, R. (1994). Ambidextrous thinking. *Innovations in Mechanical Engineering Curricula for the 1990s*.

Freire, J., & Alarcón, L. F. (2002). Achieving lean design process: Improvement methodology. *Journal of Construction Engineering and Management*, *128*(3), 248–256.

Friedman, B., Kahn, P., & Borning, A. (2002). Value sensitive design: Theory and methods. *University of Washington Technical Report*, 2–12.

Gasparini, A. (2015). Perspective and use of empathy in design thinking. In *ACHI, The Eight International Conference on Advances in Computer-Human Interactions* (pp. 49–54). Retrieved from http://www.academia.edu/download/36907810/gasparini-final-3.pdf

Gestwicki, P., & McNely, B. (2012). A case study of a five-step design thinking process in educational museum game design. *Proceedings of Meaningful Play*. Retrieved from http://meaningfulplay.msu.edu/proceedings2012/mp2012_submission_37.pdf

Glen, R., Suciu, C., & Baughn, C. (2014). The need for design thinking in business schools. *Academy of Management Learning & Education*, *13*(4), 653–667.

Goldenberg, J., Mazursky, D., & Solomon, S. (1999). Toward identifying the inventive templates of new products: A channeled ideation approach. *Journal of Marketing Research*, 200–210.

Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. *Design Studies*, *15*(2), 158–174.

Hartmann, B., Klemmer, S. R., Bernstein, M., Abdulla, L., Burr, B., Robinson-Mosher, A., & Gee, J. (2006). Reflective physical prototyping through integrated design, test, and analysis. In *Proceedings of the 19th annual ACM symposium on User interface software and technology* (pp. 299–308). ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1166300

Hasso Platner. (2006). An Introduction to Design Thining. Process Guide.

Henry. (2016, October 9). Traffic fatalities up sharply in 2015 [Text]. Retrieved February 26, 2017, from https://www.nhtsa.gov/press-releases/traffic-fatalities-sharply-2015

Hobbs, B., & Kameshwar, P. (2013). 2013 Reliability & Markets Peer Review - Day 1 Presentations | Department of Energy. Retrieved February 26, 2017, from https://energy.gov/oe/downloads/2013-reliability-markets-peer-review-day-1-presentations

Hoffman, P., & Bryan, W. (2012). *LARGE POWER TRANSFORMERS AND THE U.S.ELECTRIC GRID*. Department of Energy. Retrieved from https://energy.gov/sites/prod/files/Large%20Power%20Transformer%20Study%20-%20June%202012_0.pdf

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design thinking: past, present and possible futures. *Creativity and Innovation Management*, *22*(2), 121–146.

Jonson, B. (2005). Design ideation: the conceptual sketch in the digital age. *Design Studies*, *26*(6), 613–624.

Joosten, T., Bongers, I., & Janssen, R. (2009). Application of lean thinking to health care: issues and observations. *International Journal for Quality in Health Care*, *21*(5), 341–347. https://doi.org/10.1093/intqhc/mzp036

Kelley, D., & Kelley, D. (2006). Design thinking. *Accessed November*, *26*, 2014.
Kembel, G. (2009). *Awakening creativity*. Retrieved from http://fora.tv/2009/08/14/George_Kembel_Awakening_Creativity
Kimbell, L. (2011). Rethinking design thinking: Part I. *Design and Culture*, *3*(3), 285–306.
Kouprie, M., & Visser, F. S. (2009). A framework for empathy in design: stepping into and out of the user's life. *Journal of Engineering Design*, *20*(5), 437–448.
Kumar, V., Duncan, A. K., & Breslin, M. A. (2009). Innovating health care delivery: the design of health services. *Journal of Business Strategy*, *30*(2/3), 13–20.
Le Dantec, C. A., Poole, E. S., & Wyche, S. P. (2009). Values As Lived Experience: Evolving Value Sensitive Design in Support of Value Discovery. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1141–1150). New York, NY, USA: ACM. https://doi.org/10.1145/1518701.1518875
Lennertz, B. (2016, May). *The Charrette System Training*. Training certification.
Lennertz, W. R., & Lutzenhiser, A. (2014). *The charrette handbook:: the essential guide for accelerated, collaborative community planning*. American Planning Association.
Leong, B. D., & Clark, H. (2003). Culture-based knowledge towards new design thinking and practice—A dialogue. *Design Issues*, *19*(3), 48–58.
Lindberg, T., Meinel, C., & Wagner, R. (2011). Design thinking: A fruitful concept for it development? In *Design thinking* (pp. 3–18). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-13757-0_1
Martin, R. L. (2009). *The design of business: why design thinking is the next competitive advantage*. Harvard Business Press. Retrieved from https://books.google.com/books?hl=en&lr=&id=CvpAgm8dQQkC&oi=fnd&pg=PR1&dq=design+thinking+applications+in+business&ots=U_AN8a9qnU&sig=nqswusSw9RWSZHpUnpYeEShgaa8
Murty, P., Paulini, M., & Maher, M. L. (2010). Collective intelligence and design thinking. In *DTRS'10: Design Thinking Research Symposium* (pp. 309–315). Retrieved from https://pdfs.semanticscholar.org/fdca/6856037ab7bdf83f8fb16d8c4fe1879d86c4.pdf
Osman, H., El-Gohary, N., & El-Diraby, T. (2007). Integrating Value Engineering and Context-Sensitive Solutions: The St. Clair Avenue West Transit Improvements Project. *Transportation Research Record: Journal of the Transportation Research Board*, *2025*, 81–89. https://doi.org/10.3141/2025-08
Oxman, R. (2004). Think-maps: teaching design thinking in design education. *Design Studies*, *25*(1), 63–91.
Ozorhon, B. (2012). Analysis of construction innovation process at project level. *Journal of Management in Engineering*, *29*(4), 455–463.
Plattner, H., Meinel, C., & Leifer, L. (2010). *Design thinking: understand–improve–apply*. Springer Science & Business Media.
Qi, W. (2009). Design Thinking and Product Design. *Art and Design*, *11*, 76.
Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330–348.
Rowe, P. G. (1987). Design Thinking MIT Press. *Cambridge, MA*, *28*.
Rowe, P. G. (1991). *Design thinking*. MIT press. Retrieved from https://books.google.com/books?hl=en&lr=&id=ZjZ3mflzJtUC&oi=fnd&pg=PA1&dq=design+thinking+peter+rowe&ots=K6beA_4vD5&sig=lBfIjGXAt6GjpstsKqfK3nanrvw
Segerstedt, A., Olofsson, T., & Erik Eriksson, P. (2010). Improving construction supply chain collaboration and performance: a lean construction pilot project. *Supply Chain Management: An International Journal*, *15*(5), 394–403.
Shah, J. J., Smith, S. M., & Vargas-Hernandez, N. (2003). Metrics for measuring ideation effectiveness. *Design Studies*, *24*(2), 111–134.
Tam, V. W. Y., & Hao, J. J. L. (2014). Prefabrication as a mean of minimizing construction waste on site. *International Journal of Construction Management*, *14*(2), 113–121. https://doi.org/10.1080/15623599.2014.899129
US EPA, O. (2014). Sources of Greenhouse Gas Emissions [Overviews and Factsheets]. Retrieved February 26, 2017, from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
US EPA, O. (2016). U.S. Greenhouse Gas Inventory Report: 1990-2014 [Reports and Assessments]. Retrieved February 26, 2017, from https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014
van der Hoven, J., & Manders-Huits, N. (2009). *Value-Sensitive Design*. Wiley Online Library.
Vredenburg, K., Mao, J.-Y., Smith, P. W., & Carey, T. (2002). A survey of user-centered design practice. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 471–478). ACM. Retrieved from http://dl.acm.org/citation.cfm?id=503460