Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

EDITOR'S DESK

This issue guest edited by Professor Amaresh Chakrabarti is quite unique and the editorial committee and I are very excited to bring out this series of review articles as the year 2015 comes to an end.

The reviews are meticulously designed and span over several areas in design science particularly focusing on the phenomenon followed by evaluating the nature of design and creativity, design and collaboration and design and information. The uncanny knack with which the latter half reviews are developed concerning the economical, ecological and other artefacts clearly show the ability of Amaresh to plan and execute design science. Overall, this is a remarkable collection of review articles for students, faculty, experts, advisors and entrepreneurs in "Design".

I would like to assure the readers of continued coverage of reviews pertaining to areas of current interest in science and technology in the forthcoming year 2016.

T.N. Guru Row
Editor
ssctng@sscu.iisc.ernet.in

Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

GUEST EDITOR'S DESK

Design Science: Theories, Methods and Tools

Design has many definitions. In some, it signifies a *process* or *activity*—the act of designing. In others, it is an *outcome*—the designs created as a result. Discussion of design science (also called design research) needs a definition of design that is generic enough to encompass its research community, embracing all sorts of designs and designing, and all associated phenomena. Simon (1969) defined design as "a purposeful activity aimed at changing existing situations into preferred ones." Adapting this, we define *a design as a plan for intervention* which, when implemented, is *intended* to change an undesirable situation into a (less un-) desirable one. *Designing is the process* of identifying these situations as well as developing designs to support the transition (Chakrabarti 2009). This definition captures several essential, generic features of design (see Chakrabarti 2011; 2015):

- Designs are plans for intervention that *may or may not include physical artefacts*.
- The concepts of undesirable and desirable situations are essential to the act of designing: *without an undesirable situation, there is no designing*.
- Designing involves identifying these situations *as well as* developing the plan with which to change the undesirable into the desirable.
- It is the *implementation* of the design, and not the design itself, that actualizes change: designing and implementing (e.g. manufacturing) are *both crucial* in bringing about the change.
- A design is implemented with the *hope* that it would usher in the desired change, which may or may not happen; *hence the need for design science*.

Design science (DS) involves developing design knowledge with which to inform and improve design practice and education. This knowledge is of two kinds: *descriptive knowledge* that provides understanding of *design phenomena*; and *prescriptive knowledge* for improvement of design, in the form of support such as frameworks, guidelines, methods and tools, that are developed using descriptive knowledge as their basis (Blessing and Chakrabarti 2009).

Design phenomena is defined as those *that govern design and its relationships with its facets*; *facets* are the aspects that influence and are influenced by design, such as people, organisation, knowledge and tools, artefacts, processes, economy, and ecology. Design science, therefore, develops knowledge of *design* and its *relationships* with its facets so as to better inform and support design practice and education.

Let us compare design science with similar disciplines. The central goal of the discipline of medicine is to support medical practice and its education. To achieve this, medicine develops descriptive knowledge of how organisms and their health work; and prescriptive support (e.g. medicines or surgical procedures) to control health of these organisms. Economics supports economic practice and education by developing descriptive knowledge of how economy works, and prescriptive interventions for its control.

Design science too has both descriptive and prescriptive goals (Blessing and Chakrabarti 2009). Its descriptive models and theories provide the basis on which prescriptive support is developed. The distinction, however, is in its explicit focus on design phenomena: it is this focus on design and its links to the facets that distinguishes design science. For instance, creativity per se may not be an area of design science, and typically belong to cognitive psychology. Design creativity, however, belongs to design science, as it explores the nature of creativity in, and the influences of creativity on, designing.

Design science is a young discipline, with barely fifty years of presence as a formal research community (Chakrabarti and Lindemann 2016). It has, however, grown rather rapidly during this period. Its first research workshop was organised as late as in 1962 (Jones and Thornley 1962), but a dozen design conferences now take place each year. The number of papers in the biennial Design Conference in Croatia grew steadily from 127 to 230 during 1998–2004 (Pavkovic et al 2004). ICoRD—India's flagship

Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

research conference in design—saw a fourfold increase in the number of papers and participants within a decade (Chakrabarti 2015). From only a few in the 1970s, the number of peer-reviewed journals in design science has grown now to over twenty five. The number of design research laboratories in the USA alone has grown from a few in the 1980s to at least five times now. In India, the number of programmes teaching design grew from a few at the turn of the millenium to over thirty now, training thirty times as many students to become design professionals. During this period, the number of research programmes in design in India grew from none to ten, training several hundred students.

Even within this short period of formal existence, design science has significantly impacted design practice. Based on a study of 410 new product development (NPD) projects conducted with feedback from experienced product development managers and project managers in 209 manufacturing companies that operate their own NPD from bases in Germany, Austria and Switzerland, Graner (2016) found that applying design methods in NPD led directly to superior financial performance of the product developed, and indirectly to a greater degree of innovativeness, better cross-functional collaboration and shorter time to market. Based on the findings of an comprehensive innovation study conducted by the Product Development & Management Association (PDMA) in the USA, Barczak et al. (2009) report that: "In terms of aspects of NPD management that differentiate the 'best from the rest', the findings indicate that the best firms […] use numerous kinds of new methods and techniques to support NPD."

This special issue on Design Science contains seven review articles.

In the first article "A Review of Theories and Models of Design", Chakrabarti and Blessing provide an overview of the "rich legacy" of theory and model development in design science, and identify several major areas for further research by addressing the following questions: "What are the major theories and models of design? How are design theory and model defined, and what is their purpose? What are the criteria they must satisfy to be considered a design theory or model? How should a theory or model of design be evaluated or validated? What are the major directions for further research?"

The second article "Studies of Design Creativity: A Review and its Prospects", by Nagai and Taura, provides an overview of studies on design creativity by analyzing them in two aspects: the foundations of design creativity, and the role of criticism in enhancing design creativity. It proposes how design critics could enhance creativity and innovation in designs by evaluating "practitioners and assuming responsibility for guaranteeing the quality" of the profession.

The third article "Collaborative Design", by Törlind, provides an overview of research in the area of design collaboration. "Global cooperation is a reality for most engineering design teams today", both within the organisation and across its supply chains. This review focuses on interpersonal communication in collaborative design, where small teams of interdisciplinary stakeholders work together to reach a common goal that could not be accomplished alone by any individual stakeholder.

In the fourth article "Design Informatics: Supporting Engineering Design Processes with Information Technology", McMahon takes engineering design as "an information processing activity" where information is created and used at every stage of designing. The review takes a critical look at the various technologies used for design informatics, e.g. "computer-aided design, computer-aided engineering, computer-supported collaborative work, design-for-X and knowledge and information management", to identify major landmarks of progress and major directions for further research.

"Whether they know it or not, everything designers do influences cost issues, which can be crucial for success on the market". With this as the motivation, Mörtl and Schmied in the paper "Design for Cost—A Review of Methods, Tools and Research Directions", critique research in the area of design for cost, to report the major findings on the impact of cost on engineering design, and the major achievements in this area. The review also presents a framework for cost reduction in projects.

Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

In the sixth article, "Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation", Pigosso, McAloone and Rozenfeld take Ecodesign as "a proactive management approach that integrates environmental considerations in product development and related processes" so as "to improve environmental performance of products throughout their life cycle". Their review finds "an intense development of new ecodesign methods and tools, but uptake by the industry remains a challenge."

In the final article, "Advances in Designing Product-Service Systems", Vasantha, Roy and Corney focus on Product-Service Systems (PSS), which "emerged as a class of hybrid business models that have evolved particular relevance to enterprises operating in a resource-efficient, circular economy". To identify research gaps and directions for future research, the paper reviews PSS research in four major areas: "PSS ontology, requirements definition, design process support for generating PSS concepts, and the evaluation of PSS concepts".

Together, the reviews cover all major facets of design mentioned earlier in this editorial, and both aspects of design phenomena: (i) exploring the nature of *design,* and (ii) exploring its *relationships* with the facets. The first article reviews theories and models of design, *exploring the nature of design*—the first aspect of design phenomena. The remianing six articles explore the *nature of relationships* of design with its various facets. The article on design creativity focuses on the relationships between design and *creativity*—a *people* facet. The article on collaborative design reviews research that explores the relationships between design and *collaboration*—an *organisation* facet. The article on design informatics reviews research that explores the relationships between design and *information*—a *knowledge & tools* facet. The article on design for cost focuses on the relationships between design and *cost*—an *economy* facet. The article on eco-design focuses on the relationships between design and *environment*—an *ecology* facet. The final article, on PSS, reviews research on design and its relationships to systems that provide both *products* and *services*—a combination of *artefact* and *process* facets.

The reviews also demonstrate the highly multi-disciplinary character of design science, where research must embrace, adapt and synthesise paradigms from diverse disciplines represented by design and its facets. The authors too represent a highly international community, spanning ten universities from seven countries in two continents.

A note on the design of the cover page. Designed by Kumari MC of the Centre for Product Design and Manufacturing at IISc and myself, the cover page celebrates design science and some of its major milestones. The white page in the hexagon on the left is the first page of my copy of the first edition of the celebrated book "Engineering Design" by Gerhard Pahl and Wolfgang Beitz (Pahl and Beitz, English edition 1984) that revolutionised the teaching of engineering design. The photographs around the page are those of late Professors Beitz (top left) and Pahl (bottom left) who wrote the German version of the book, of Professor Ken Wallace (bottom right) who translated and edited the German version, and of late Donald Welbourn (top right) who brought these three together. The figure at the top right of the cover page depicts John Gero's FBS model (Gero 1990)—one of the most influencial descriptive models of design. The figure at the bottom right of the page depicts DRM (Blessing and Chakrabarti 2009)—one of the most widely used methodologies for carrying out engineering design research. The leftmost person in the group photograph (middle right on the page) is Vladimir Hubka, who founded 'Workshop Design Konstruktion' (WDK)—an association of academics that evolved into the Design Society—the largest international peer body in engineering design science. Some of the remaining figures are from the papers in this special issue; the others include screenshots of theories, models, and tools for design—representing both descriptive and prescriptive characters of design science. The colours allude to the colours of Springer, who have always remained the main disseminator of research in this area. One might spot a 'D' and an 'S' in the background, depicting the dominant role design plays in design science.

Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

I am grateful to Professors TN Guru Row and GK Ananthasuresh, for their kind offer for me to act as a Guest editor for the Journal. I am also thankful to Ms Kavitha Harish, for her continuous engagement to ensure that the editorial progress for the special issue remained steady and reasonably on time. Finally, I thank all the authors for their kind acceptance of my invitation and their effort in writing the articles.

References

1. G. Barczak, A. Griffin and K.B. Kahn, Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA Best Practices Study, *Journal of Product Innovation Management*, **26**(1), 3–23 (2009).
2. L.T.M. Blessing and A. Chakrabarti, DRM, a design research methodology. Springer, London (2009).
3. A. Chakrabarti, Design Creativity Research at IdeasLab, IISc. In Raghavan, NR Srinivasa, and Cafeo, JA. (eds) The Art and Science Behind Successful Product Launches, Springer (2009).
4. A. Chakrabarti, In: Papalambros, PY (2015) Design Science: Why, What and How. Design Science, **1**, e1, (2015), doi:10.1017/dsj.2015.1.
5. A. Chakrabarti, Towards a Taxonomy of Design Research Areas, Herbert Birkhofer (ed), *The Future of Design Methodology*, Springer, pp. 249–260 (2011).
6. A. Chakrabarti and U. Lindemann, Impact of Design Research on Industrial Practice: Tools, Technology and Training, Springer, Switzerland, (2016), doi 10.1007/978-3-319-19449-3.
7. J. Gero, Design prototypes: a knowledge representation schema for design, *AI Magazine*, **11**, 26–36 (1990).
8. M. Graner, Are Methods the Key to Product Development Success? An Empirical Analysis of Method Application in New Product Development, In A. Chakrabarti and U. Lindemann (eds.), *Impact of Design Research on Industrial Practice*, Springer, Switzerland, (2016), doi 10.1007/978-3-319-19449-3_2, pp. 23–43.
9. J.C. Jones and D.G. Thornley, Conference on design methods. Pergamon Press, Oxford. UK (1963).
10. G. Pahl and W. Beitz, Engineering Design: A Systematic Approach, 1st Ed., Design Council and Springer London 1984; translated and edited by Wallace KM.
11. N. Pavkovic, M. Storga, D. Dekovic and D. Marjanovic, Towards more efficient organisation of design society conferences. *Proceedings of the 8th International Design Conference DESIGN 2004*, D. Marjanovic (ed), pp. 1375–1382 (2004).
12. H.A. Simon, The Sciences of the Artificial. MIT Press, Cambridge, Mass, 1st edition (1969).

Prof. Amaresh Chakrabarti
Centre for Product Design and Manufacturing,
Indian Institute of Science,
Bangalore 560012,
India.
ac123@cpdm.iisc.ernet.in