RE-ENGINEERING DESIGN THROUGH MULTIPLE DISCIPLINARY LENSES

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ABSTRACT
Models of design tend to contain activities that relate to multiple disciplinary and professional fields. The rapid advancement of technology and the increasing social, economic, and environmental challenges demand more sophisticated models of the design process. The term "design process" captures a wide variety of views and practices in different disciplines such as engineering, business and product design. This paper starts by examining the interdependencies and relationships between design activities across disciplines to then focus on engineering design as a specific case. The aim is to formulate an inter-disciplinary approach that informs and guides flexible design approaches. The resulting approach is subsequently compared to conventional educational approach in engineering, business, and product design. The paper closes with a categorised overview of the academic literature on design process from various disciplinary lenses. This work gives researchers and educators an understanding of the breadth and depth of design process, and the connectivity across disciplines during the development of new products and services.

Keywords: Design models, business, engineering, product design.

1 INTRODUCTION

It has been argued that design is experiencing a disciplinary crisis [1]. Indeed, in many examples of design research an established method or methodology is often discarded in favour of a "pick and mix" approach to selecting and applying a number of different methods [2]. This "bricolage" approach is a form of methodological reinvention, driven by the need for flexibility [2] and considered by some to be evidence to support the state of crisis [3]. However, such methodological reinvention is arguably an outcome of design moving beyond its disciplinary framework in order to enhance connections between disciplines and an indication that design is maturing as a discipline [3]. Whilst methodological reinvention appears to be occurring in design research, it has been noted that design problems can no longer be solved without prior or parallel research [4]. It is therefore possible that the bricolage approach will translate into design practice as much as design research.

Yet for the practicing designer there is little guidance on how to select methods, tools or approaches that exist outside of their normal practice. Given that one of the main goals of research in design disciplines is to support and improve design practice [5] it seems timely to consider how to support designers with appropriate tools, techniques and approaches that embrace the fact that design allows connection across multiple disciplines. This paper therefore reviews design knowledge in three different design disciplines to identify how design is perceived and conducted, and therefore to understand the challenges that exist in sharing design tools across different perspectives of design. The paper proposes that the education of designers in different disciplines should explicitly embrace and expose students to different disciplinary approaches to design to prepare them for employment in an increasingly complex world by providing them exposure to different design tools that they can utilise.

2 KNOWLEDGE OF DESIGN THROUGH MULTIPLE DISCIPLINARY LENSES

The term design covers a broad field of activities from the systematic processes of engineering to the artistic processes of haute couture. There are elements of design that are common to all or most of the fields of design but still it should not be assumed that the term has equal meanings to all designers [6]. The following sections outline three different areas of design and attempts to characterise their practice in general terms to provide an initial set of disciplinary lenses through which to examine design as a whole.

2.1 Engineering Design

There would be few who disagreed that engineering design is a recognized activity, yet there is little consensus on how it is embodied in practice. One common view is that design is the essence of engineering, an aspect of human ingenuity upon which the competitiveness of countries depend [7]. Yet the boundaries of engineering design are somewhat fuzzy. For instance, mechanical engineering design overlaps product design, but also, to a smaller extent, technology development [8]. Engineering design has been understood to be a partially scientific discipline.

Pahl and Beitz [9] write that the main task of engineers in the context of design is to "apply their scientific and engineering knowledge to the solution of technical problems, and then optimize those solutions within the requirements and constraints set by the material, technological, economic, legal, environmental and human-related considerations". This view is shared by the engineering accreditation bodies. For example, the Institution of Professional Engineers New Zealand (IPENZ) identifies one of the core competencies of an engineer as the ability to "design or develop solutions to complex engineering problems in accordance with good practice for professional engineering" [10].

In an attempt to understand how designers approach problem solving, Lawson [11] utilised a set of tasks around organising 3D coloured blocks subject to certain undisclosed rules. He observed that scientists generally adopted a generally problem-focused strategy by attempting to understand the fundamental rules defining the problem. However the architects adopted a solution-focused approach that involved proposing a series of solutions, and to have these solutions eliminated, until they found an acceptable one. As a partially scientific discipline, engineering design typically involves attempting to fully explore a design problem to identify the best solution. This is in contradiction of the view that design tasks are not problems that can be answered with correct or optimum solutions [6].

2.2 Product Design

Product design is a highly involved, complex and iterative process and the needs and specifications of the required artefact get more refined only as the design process moves toward its goal. The type of design knowledge is formal, tacit, process oriented, compiled and dynamic. Design problems are more often termed as "wicked" problems rather than technical. Thus, design may require a complex structure and interactions of a large number of areas/disciplines to obtain desired outcome. Product design differs from engineering design in that it is not a search for the best solution to a constrained problem, but an exploration for creative solutions to a more loosely defined need.

Product design is therefore more an iterative process to understanding the nature of the problem under consideration as a means to understand the problem itself. It involves a multi-stage, iterative and collaborative process with extensive communications and coordination among teams of experts and the end users [12].

In the iterative design process, if the problem is ill defined at the discovery stage it puts a strain on the end outcome of the process. There is enormous pressure on the designer in terms of demands for a faster turnaround time, lower margin for error, efficiency in managing resources not just for the product but also for the design process, a greater need to collaborate in multidisciplinary teams. Design process puts too much emphasis on the desirability aspect of the product and less on feasibility and viability of the output, which is crucial for business to survive.

2.3 Business Design

Designers develop and make ideas more attractive to consumers but in an increasingly global market companies are asking them to create ideas that better meet consumers' needs and desires. The former is tactical and results in value creation (product design) and the latter is strategic and leads to dramatic new forms of value for businesses [13]. It is termed as business design.

The objectives of business design are no longer just physical products; they are new sorts of processes, services, IT-powered interactions, entertainments, and ways of communicating and collaborating—especially in human-centred activities in which design can make a decisive difference. Characteristics of business design include it being multi perspective, experimental, integrative thinking, optimistic and collaborative.

Business design is therefore a human-centred approach to innovation. It applies the principles and practices of design to help organizations create new value and new forms of competitive advantage. At its core, business design is the integration of customer empathy, experience design and business strategy.

3 DESIGN AS A TRANSDISCIPLINARY META-DISCIPLINE

There has been much debate in the literature as to whether design is a discipline or not. For example, Cross [14] suggests that there has been a major shift in focus within design research towards the aim of creating a design discipline as opposed to a science of design. Meanwhile, Bremner and Rogers [1] suggest that design should be independent of discipline. One approach to resolving these different views is to consider design as a meta-discipline that both cuts across and draws together other disciplines. This approach allows the resolution of tensions in design by considering the multitude of perspectives that arise when using different disciplinary lenses.

Figure 1 is a hierarchy of disciplines as proposed by Max-Neef [15] that places disciplines at different levels, namely the value, normative, pragmatic and empirical levels.

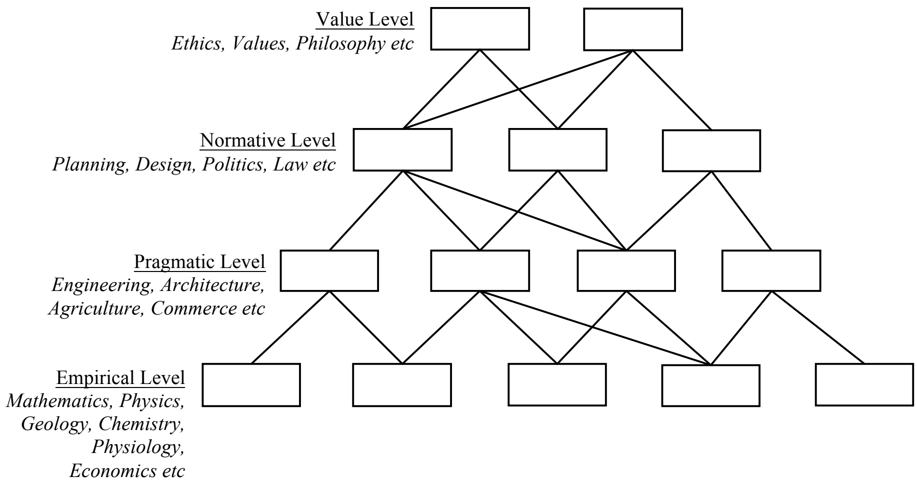

Figure 1. Hierarchy of disciplines (Adapted from [15])

Each level in the hierarchy can be considered as a question. For example, disciplines at the empirical level relate to the physical laws of nature and the principles that drive life and societies. This level asks and answers the question "what exists?". The next level is composed mainly of technological disciplines that answer the question "what are we capable of doing?". What this level does not tell us, is whether our capacities should be implemented. The danger often is that we do things simply and only because we know how to do them. The normative level asks and answers the question "what is it we want to do?". The value level asks and answers "what should we do?" or rather "how should we do what we want to do?".

If design were a discipline then it sits in the correct level of the hierarchy, as design very much deals with the question "what is it that we want to do?". However, thinking of design as a discipline in its own right creates tension in particular instances of design. This is no more apparent than considering the domain of engineering design. Engineering is at the pragmatic level within Max-Neef's hierarchy, yet traditional delivery mechanisms with in engineering programmes predispose engineers to thinking that perhaps they work at an empirical level. An engineer working on a design task may therefore find themselves pulled in multiple directions as they attempt to rationalise across the various thinking modes corresponding to these three levels of the hierarchy.

Different modes of interdisciplinarity exist [16] and Max-Neef [15] describes interdisciplinarity as a collaboration between two levels of the hierarchy, whereas transdisciplinarity is a collaboration across all four levels driven by the value level. In this regard, engineering design is by definition an interdisciplinary endeavour. It is, however, just one slice through the meta-discipline of design that is taught, practiced and researched in a particular manner. Whilst this does not detract from engineering design as such, it is possible to change how engineering designers understand design as a meta-discipline by using multiple disciplinary lenses to examine complex design tasks. The following section outlines conventional approaches to engineering design education before an alternative is proposed in section 4.

4 CONVENTIONAL APPROACHES TO ENGINEERING DESIGN EDUCATION

This paper utilises engineering design as an example of how different disciplinary lenses can be applied to an understanding of a particular design approach in order to suggest alternative approaches for the teaching of design. It has been noted that the classical model of engineering education begins with a solid grounding of theory, and is driven by the scientific method of enquiry. This approach can be criticised as it allows little scope for creativity. As students progress through their engineering degree, they are typically exposed to an increasing degree of practical learning, but this is built on predetermined theoretical foundations and so the students approach their applied work constrained – and supported - by their learning development [17].

Whilst there are exceptions, such as the use of challenge based learning in introductory engineering design courses [18], most engineering degrees first introduce engineering design "in the small", even at the most well regarded institutions. This often is the introduction of how to create models and assemblies in computer aided design (CAD) software, how certain components operate and how to integrate these components in to a working system to solve some form of design challenge, for example the design and development of an autonomous robot to find and move objects in a constrained space. Such courses are often described as having an "emphasis on the creative design process", yet do not deal explicitly with creativity in practice and only introduce a relative small number of ideation methods in a relatively superficial manner.

This view of design can directly be attributed to the accreditation requirements that specify design as a technical activity. This implies that the engineer is only involved in the problem solving process after the wider context is decided and the outcome provided to the engineer as a set of constraints that bound the engineering problem under consideration. This is often reflected in the teaching of engineering design, which focuses on introducing students to design in relatively well-defined problems. This raises questions about the context of design activities, and suggests that "solution of technical problems" is only a limited perception of design as a whole. Whilst not addressed in this paper, there are opportunities to consider how an engineering curriculum holistically integrates with the social sciences to provide a greater understanding of how engineers can engage with problems in advance of the production of the engineering specification.

This paper does not criticise the conventional approach to teaching engineering design. When viewed from its own disciplinary lens, the conventional approach is wholly appropriate in terms of the goals of engineering design. Indeed, there is significant value in using this particular lens in the education of other design disciplines to help students gain insight in to the body of knowledge associated with engineering design. With this in mind, this paper asks whether the introduction of design from other disciplinary lenses has the potential to broaden an engineering designer's knowledge of design, and better enables them to take part in design problems in a broader context.

5 AN ALTERNATIVE APPROACH TO TEACHING ENGINEERING DESIGN

If design is considered a transdisciplinary meta-discipline, then the purpose of applying different disciplinary lenses to a given design activity should be to help prepare a designer to take part in complex, transdisciplinary design activities. Referring to Figure 1, this would involve having a designer integrate knowledge and practices from across all four levels of the hierarchy. As engineering tends to be driven by a scientific mode of enquiry, the main purpose of applying different disciplinary lenses would be to focus on the value and normative aspects.

The role of values in design is becoming of increasing interest [19, 20] and has the potential to alter the commonly held view that technology is value-neutral. To this end, exposing engineering students to design through the business design lens has the potential to suggest that there is a need for clarification and explanation of the overall (ethical) objective of a project and promote the integration of moral values in a design task. Projects and workshop in business design provides a learning experience that is better at supporting students in learning, not only disciplinary fundamentals, but also personal and interpersonal dimensions. For instance, a current group of students are working with a local transport agency to explore how the walls of railway tunnel can be used in an effective way. This includes at the possibility of designing interactive installations inside the tunnel with sound and light effects. Students would be exposed to challenges and knowledge from different disciplines such as design, creative technologies, business, spatial design and user experience of travellers. In particularly, the project raises questions around values and ethics, with the former being focused on the traveller experience and the latter about whether to include advertising in the tunnels. In projects such as these, engineering students would be exposed to solving problems that are ill-structured and complex, and requiring collaborative activity to gauge and understand the implications of any design decision and its impact on the travellers experience.

A challenge exists in terms of how to integrate project based inquiry and a more broad consideration of creative solutions, societal and economic factors into an engineering curriculum. The obvious solution is to use design courses as the vehicle for such change, however this has the potential to further reinforce the difference between design and the supposedly more theoretical elements of an engineering curriculum. An alternative solution is to embrace design within those other elements of the curriculum and at the same time promote problem space rather than understanding the solution space. For example, a relatively common exercise in a statics class would be the design of a structure to fit a given space envelope with the design goal of maximising the load it will bear. The same theoretical knowledge can be obtained by considering a more open ended challenge such as a need to transport humanitarian supplies across a gorge in a remote area. Students can be encouraged to consider a wide range of possible solutions, along with the implications of each, with the knowledge to be gained delivered through a consideration of the design evaluation conducted to choose a final solution that is based not just on the technical requirements but also the wider social and economic requirements.

Whilst design would be considered as a normative discipline, there is still a need to reinforce the normative aspects of design. Normative views of the engineering design process would reinforce the technical aspects of engineering, which suggest that design is a well-defined procedure that starts with a concept and steadily progresses through detail to manufacture, yet expands to include the social reality of a design task. This can be achieved by adopting a product design lens. For instance, groups of students are currently working towards designing better healthcare experiences for patients, families, and staff. As the problem is vaguely defined, students can pursue multiple solutions that may be include the design of products, services, systems, and experiences for the improved health and wellbeing of all hospital users. Engineering students working on a project such as this would gain experience of solving problems with a more meaningful way by considering that there may be a non-technical solution that offers advantages over technical solutions.

6 CONCLUSION

This paper has suggested that design is more than a discipline, but instead a transdisciplinary meta-discipline that both cuts across and draws together knowledge from different domains. Design is therefore multi-faceted, where each face (or lens) represents a particular perspective of what design entails. Each perspective of design is consistent and coherent in its own way, but this paper argues that any designer would benefit from being exposed to a shift in perspective that allows them to experience design as perceived in a different domain.

Thinking of design education in this way would pave the way towards a new generation of designers who are more prepared to adapt their design processes to accommodate tools and approaches from different disciplines, and who are more conversant with other perspectives. Such familiarity fosters an increased capacity to collaborate on the increasingly complex problems that face designers.

Whilst this paper focuses on using different disciplinary lens to bear on engineering education, this is not to criticise this domain. Instead, it is just but one example of the underlying argument that all design education can benefit from adopting different disciplinary lenses and exposing students to different models and knowledge about design.

REFERENCES

[1] Bremner, C. and P. Rodgers, *Design without discipline.* Design Issues, 2013. **29**(3): p. 4-13.

[2] Yee, J. and C. Bremner. *Methodological bricolage: What does it tell us about design?* in *Doctoral Education in Design Conference*. 2011. Hong Kong.

[3] Law, J. and J. Urry, *Enacting the social.* Economy and society, 2004. **33**(3): p. 390-410.

[4] Bonsiepe, G., *The Uneasy Relationship between Design and Design Research*. Design Research Now: Essays and Selected Projects, ed. R. Michel. 2007, Basel: Birkhäuser Basel. 25-39.

[5] Stolterman, E., et al. *Designerly tools*. in *Undisciplined! Design Research Society Conference*. 2008. Sheffield.
[6] Falin, P. *The Social Dimension in Construction of Designerly Knowing*. in *Nordes 2007 - Design Inquiries*. 2009. Oslo, norway: Nordic Design Research.
[7] Koen, B.V., *Toward a strategy for teaching engineering design.* Journal of Engineering Education, 1994. **83**(3): p. 193-201.
[8] Levy, R., *Science, technology and design.* Design Studies, 1985. **6**(2): p. 66-72.
[9] Pahl, G. and W. Beitz, *Engineering design: A systematic approach*. 2nd ed. 2013, London: Springer-Verlag.
[10] IPENZ *Engineers Mobility Forum Agreement and APEC Engineer Agreement Updated Assessment Statement* 2005.
[11] Lawson, B.R., *Cognitive strategies in architectural design.* Ergonomics, 1979. **22**(1): p. 59-68.
[12] Chandrasegaran, S.K., et al., *The Evolution, Challenges, and Future of Knowledge Representation in Product Design Systems.* Computer Aided Design, 2013. **45**: p. 204-228.
[13] Brown, T., *Design Thinking*, H.B. Review, Editor. 2008.
[14] Cross, N., *From a Design Science to a Design Discipline: Understanding Designerly Ways of Knowing and Thinking*, in *Design Research Now: Essays and Selected Projects*, R. Michel, Editor. 2007, Birkhäuser Basel: Basel. p. 41-54.
[15] Max-Neef, M.A., *Foundations of transdisciplinarity.* Ecological economics, 2005. **53**(1): p. 5-16.
[16] Connor, A.M., et al., *Problem solving at the edge of disciplines*, in *Handbook of Research on Creative Problem-Solving Skill Development in Higher Education*, C. Zhou, Editor. 2016, IGI Global: Hershey, PA.
[17] Loy, J. and S. Canning, *Clash of Cultures: Fashion, Engineering, and 3D Printing*, in *Creative Technologies for Multidisciplinary Applications*, A.M. Connor and S. Marks, Editors. 2016, IGI Global: Hershey, PA. p. 25-53.
[18] Connor, A.M., S. Karmokar, and C. Whittington, *From STEM to STEAM: Strategies for Enhancing Engineering & Technology Education.* International Journal of Engineering Pedagogy (iJEP), 2015. **5**(2): p. 37-47.
[19] Manders-Huits, N., *What values in design? The challenge of incorporating moral values into design.* Science and engineering ethics, 2011. **17**(2): p. 271-287.
[20] Van de Poel, I., *Values in engineering design*, in *Handbook of the philosophy of science*, A. Meijers, Editor. 2009, Elsevier: Amsterdam. p. 973–1006.