Connections and distinctions:
Perspectives on design activity from industrial design and electrical engineering

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Abstract— **The goal of this paper is to provide a forum to discuss design activity from two different perspectives: industrial design and electrical engineering. We start with a general overview of design activity as defined by Larson and Dorst[1]. Next, perspectives on design are presented by two of the paper's authors, specifically in the following areas: identifying and framing design problems, design representations, the iterative process, reflection, and evaluation. Finally distinctions and connections across the perspectives are described. A deeper understanding of the differences and similarities in the perspectives of design activity across the two fields of design and engineering, that engage in design help identify spaces for shared language or where abstractions may be necessary, enabling better collaboration and thus, adding to the technical literacy of all design related areas.**

Keywords—Engineering Design; Design Education; Philosophy of Engineering

I. UNDERSTANDING DESIGN ACTIVITIES

"Design" is, all at once, the name of several professional disciplines, as a verb to describe objects and environments (as "designed"), and a fundamental daily human activity. A broad definition of design that is all encompassing to a broad audience that is engaged in the activity of design is a nearly impossible task, however, identifying the salient features of design activity is necessary in order to create a common language and allow us to begin developing an interdisciplinary model of design.

A. The Nature of Design Activity

A well-established approach to understanding an enigmatic subject like design is to define it by naming its constituent parts. Many design researchers have explored the nature of designing[1], this is true from both engineering as well as design approaches [2][3]. Lawson and Dorst [4] proposed a model of design with five groups of skills and activities: formulating, representing, moving, evaluating, and managing. Each of these groups of skills and activities as defined by Lawson and Dorst [1] and corresponding literature will be summarized in the sections that follow.

1) Formulating**.** Designers start with finding and stating design problems, understanding them and exploring them repeatedly throughout the design process. Identifying the parts or elements of a problem and defining their characteristics is an important skill in design activity[2]. Donald Schon [5] described this stage as "naming" the elements of a design situation, followed by the process of "framing" the design situation in a particular way.

2) Representing. Designers in all fields represent their ideas and thoughts externally through visual representation of their design ideas[2]; Schon[5] mentions that designers interact with representations in a conversational way. The use of representation in the design process serves both internal, abductive reasoning[3] and in communicating the design to external audiences. A designer may use many methods of representation to show different aspects of the design.

3) Moving. "Moving" captures many activities that are central to solution generation[1]. Making design moves can result in a novel solution, or in developing existing solutions and ideas.

4) Evaluating. Designers evaluate design moves, or "test" the moves, to determine if they were successful. Lawson and Dorst [1] state that designers rely on subjective and objective evaluations, making judgments on the quality of a design based on utilitarian, aesthetic, and/or virtuous criteria.

5) Managing. Finally, "managing" encompases reflecting upon the design process, as being both metacognitively aware of the flow of design activity and revisiting the central design problem-solution situation. This "reflection on action" [2] occurs simultaneous to other skills and activities in the design process as a parallel line of thought [1].

II. TWO PERSPECTIVES ON DESIGN ACTIVITY

Two of the authors of this paper were asked to provide perspectives on design activity in their respective fields. A short biography of each is presented.

Mani Mina is a faculty of electrical engineering with years of experience in industrial as well as educational settings. As a researcher and practitioner of inquiry based classes in engineering, his interests lie in technological and engineering literacy. David Ringholz is an experienced industrial designer, and a founder of the industrial design program at Iowa State University. His research interests

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

include auditory branding, electronics prototyping, instructional technology, design for diversity, small-scale manufacture, and furniture and lighting. Mina and Ringholz have conducted engineering and industrial design studios and laboratories and have lead national level workshops looking at essence, meaning, and place of design in colleges of Engineering and Design across campuses [6][7][8][9].

The third author, Melissa Rands, provided the framework for the interview questions and the analysis of the responses from an educational lens. Questions were focused into five general areas: orienting questions, design formulation, design representation, design evaluation, and design management. Questions were emailed to Ringholz and Mina separately and shared with Rands to identify connections and distinctions across the two perspectives. The responses to the questions are listed in order of Ringholz first, then Mina, in their own words.

As the goal of this paper is to provide a forum for a discussion on design activity from those who practice design in different fields, our intent is to begin a conversation on design across a disciplinary divide rather than providing the results of an empirical study on the topic.

Orienting Questions

Question 1: What do designers typically "do" in your field?

Ringholz: Industrial designers are commonly involved in all phases of a design process. Broadly defined, the process includes: discovery, ideation, refinement, commercialization, and evaluation. While industrial designers learn methods applicable to all phases, they will typically identify more or less with certain phases. For example an extroverted, human-centered designer will be drawn to the parts of the process that involve gathering insights and discussing user experience. An introverted, tech-centered designer will be drawn to computer-aided design (CAD), part design and prototyping.

Mina: Engineers start with the idea of what is to be designed and the need to address certain specifications. Specifications come from the customer's requirements. It is important for the design team to understand the reasons for the requirements: Why does the customer feel the requirements are needed? What is the rational from the customer's perspective? As designers, we need to know the intentions and needs of the customer and reasons for the need. This is to make sure we know from customers' perspectives what successful delivery entails. The project needs and requirements directly map into specifications, which then map into a systems level interconnection of what needs to be done. From here, the design cycle, as an iterative cycle, starts. From an engineering perspective, the first step is to make sure that we do not reinvent the wheel; if we have standard solutions we will use them. Engineers have to depend on their experience and tested solutions. For engineers, time is money; engineering and efficiency force engineers to reuse known solutions in new ways. It is easier to start with something that we know works than create new solutions as known solutions were initially developed with considerable costs and energy. They have been tested, so it makes more sense to start with them. That is why engineering standards are valuable as well; they are basically requirements that are done by experts in the field.

Question 2: What abilities must someone have to carry out design activity in your field, and to do it well?

Ringholz: Common skillsets for industrial designers include user-centered research, critical thinking, rapid visualization, idea generation, project management, written and verbal communication. The ability to approach a design opportunity without assuming a solution is absolutely critical for successful design activity. Innovation is not always required, but in many cases it is a measurement of design quality.

Mina: Perhaps the most important ability that engineers need to have is the knowledge to breaking down the specifications of a project into steps and connected sub-systems. Breaking the problem into tasks and sub-tasks, and identifying the needs for each, is of great value in engineering design. From an engineering perspective, the ability to find basic blocks, learn new things, utilize known solutions, and make functional connections are important. In addition the ability to use models, testing process, modification and continuing iterations are important characteristics of the engineering design process. The assumption is that engineers know the basics of their field, and if they have not used it for a while, they are capable of reviewing them and implementing them.

Design Formulation

Describe how designers in your field initially approach design problems.

Ringholz: At the problem outset, designers seek to understand as much as possible, the influential elements or vectors. Designers do not take a stated problem at face value, often times they investigate to determine if a stated problem is accurate or merely a symptom of a larger set of issues. There is tremendous benefit to this approach because problems are often poorly or inaccurately articulated. A good designer will investigate an opportunity space, seeking to give it form and definition. There are a number of tools and processes for this purpose, from casual literature review and observation to sophisticated mapping and analytical devices. The best designers move fluidly from casual to systematic in order to validate their findings.

Mina: The needs or requirements of the problem, and the definition of what we would like to do and what would constitute successful design, are the first steps in engineering design. Then we break the problem into elements or sub-systems or "blocks" in which we identify the needs, the input, the output, and functional description of the block. The connection, interconnection, and specifications come next. It is important for each step to know what we are after and how do we define successful accomplishment of that state, as this constitutes our part of specification and project requirements. For each project we have a set of functional requirements and non-functional requirements; we look into how the specifications can be broken down to functional and non-functional requirements by breaking the problems into connected sub-systems. For each subsystem we look into the requirements, then connectivity (input/output) and functionality that is needed and each step has to be validated, tested, and verified. So, for the whole project, as well as each stage, we need to identify the criteria of success: how do we test, verity, and modify the subsystem? The use of models (theoretical, numerical, CAD) are important because from an engineering perspective we need to understand the physics of the problem and can predict of how our system would function. Engineers know that they need to tweak the results to match the reality of the solution. Engineering standards provide a set of ideas, requirements, and best practices to help universally agreed criteria and best practices.

Design Representation

Describe how designers in your field represent or communicate design ideas.

Ringholz: Designers rely heavily on visual communication and learn an extensive list of styles and techniques. Designers are trained to select the most appropriate visual communication tools for their position in the design process. For example, a designer might use a collage to communicate with an end user about habits, patterns of behavior and values. Next he or she will use rapid sketching to work through a high volume of ideas or solve complex problems visually. Refined ideas can be represented through detained product renderings and diagrams. Computer-aided technical drawings are required for detailed design specification and communication between disciplines or with vendors. Visuals that depict stylistic elements and lifestyle cues are often used for marketing and sales purposes. Full and scaled three-dimensional models are also frequently used throughout the process to assess form, function, mechanics, scale, comfort, fit, finish and material properties.

Mina: We use systems-level thinking, flow charts, and systems-level connections. Each field has a way to do systems drawing and schematics. Some areas use drawing more frequently, such as mechanical systems to show how the system connects together. Most engineering fields use CAD and different CAD-related visualization tools. More abstract areas, such as electrical engineering, also have CAD systems but mostly develop circuit models or systems models with them. One of the most important items of the drawings are to show connectivity between stages and subsystems, as well as what is in each subsystem. We use interconnections, schematics, engineering drawing, CAD, 3D models, and renderings, when needed.

Design Evaluation

Describe how design ideas and processes are evaluated in your field.

***Ringholz*:** Ideally validation would be conducted at all phases of the design process. In the best circumstances, key stakeholders are invited to provide feedback. Earlier in the process the feedback is focused on the design objectives, ensure that the opportunity space is defined and framed properly. In the development and refinement phases the feedback is focused on a designs features, functions and aesthetic considerations. In most product development scenarios, the goals is to terminate "bad" or inappropriate ideas before they can move too far down the development pipeline. Generally, the longer a "bad" idea persists the more it costs the organization in hard and soft terms.

Mina: Validation is done based on specifications, standards, and functionalities. Standards are field specific; they are described, defined, and agreed on by working groups in professionals in professional societies. Each engineering professional society has their own standard groups. A critical eye is necessary at all levels, most importantly at the systems definition, systems integrations and debugging. Essentially many engineers look at the same design from different perspectives. This helps in predicting unforeseen issues that may show up under extreme conditions by modeling. However, an experienced engineering vision is as important. Measurement, testing, assessment, and examination for unforeseen conditions are always important; this is known as understanding and implementing standards and benchmarking.

Design Managing

Describe how designers in your field manage the design process.

Ringholz: There are common tools for managing the design process, but every designer seems to internalize them differently depending on the timeline and tolerance for ambiguity. Many designers like to think that they can magically bring many disparate elements together in meaningful new combinations, but the truth is that it is not possible without a reliable design process. Design development scenarios require designers to operate in a complex sphere that includes clients, vendors, collaborators and external variables that can be hard to predict. Add to that multiple, simultaneous projects. The most reliable way to evaluate progress is through reliable periodic validation with the correct stakeholder(s). Designers are trained to suspend their individual beliefs and values in order to prevent the unintentional interjection of a personal bias. Validation is an excellent way to determine whether or not a project is tracking toward the agreed objectives; it is also an effective way of resolving inevitable conflicts between collaborators.

Mina: The management of the design process highly depends on the team and project. There usually are many reviews and cross-checks in the process. Engineers break work down into system modeling and thinking. Engineers start with what each subsystem needs to do. Many times engineers start from the end; they start with what is needed and step back and make a timeline. Then engineers make modifications to the timeline for unpredictable occurrences. Defining what success is at each step helps to verify each step. It is also important to know what we can do in parallel and what has to be done sequentially. Testing and verification, which may result in iterations, need time and is usually built into the timeline.

III. Connections and Distinctions

Connections and distinctions between the two perspectives on design activity are identified when the interview answers are compared; we briefly highlight the most salient of these in discussion. While connections exist between the perspectives, the distinctions show the assumptions, biases, and differences in approach.

The beginning of design activity is described similarly in both perspectives. Mina describes "breaking down the specifications of a project into steps and connected sub-systems" while Ringholz speaks of identifying "influential elements or vectors" in the problem. Although the language differs, both carefully analyze the design problem, breaking it down into parts to fully understand what the design problem presents. However, the orientation to the problem indicates a distinction between the perspectives. Industrial designers question whether a problem is accurate or "merely a symptom of a larger set of issues." This 'questioning of the question' is an important skill of design cognition, and is at the root of what Schön [2] identified as "reframing" the design problem. Mina, on the other hand, does not discuss reorienting or reframing the problem, but assumes the root of the design problem is hidden in the project specifications. The distinction between how engineers and designers orient themselves at the entrée to a design problem is important to address, especially for interdisciplinary teams, when activating prior knowledge, creating mental models, and identifying knowledge gaps with peers is necessary [4].

We also notice that an engineering perspective relies on *known and tested* possibilities for the design solution and is focused on the technical rational properties of the problem, such as the specifications, functional and non-functional aspects, and durability and safety. Known solutions have proven their worth and standards have been established, so reasoning and rethinking the problem and solutions appear unnecessary. The industrial design approach, on the contrary, emphasizes the *possibilities* within the technical and practical realm, and is focused on the user, the user interaction, and the user's experience. The role of the industrial designer is to think about what can be ideated, created, and what other types and functionalities of the product can solve the design problem. These distinctions may be attributed the differences in predominant reasoning patterns between engineering (deductive, inductive) and design (abductive) and how they manifest in design activity in either field [2].

Connections and distinctions can also be found in how the authors speak about the evaluation of the quality of a design solution in their respective fields. Ringholz, as the industrial designer, mentions "features, functions, and aesthetics" as criteria for judgement, while Mina as the engineer mentions "specifications, functionalities, and standards". Judging a design solution against product specifications and functionality connect across the industrial design and engineering divide, while "standards" (engineering) and "aesthetics" (industrial design) are where the criteria diverge. It is important to note that design activity is not as clear and logical as the scientific method, and involves making quick value judgments between different alternatives; often there no objective metrics by which to determine its effectiveness [5]. Therefore, learning how to take both qualitative and quantitative factors into consideration when judging quality of a design solution is a necessary skill for all phases of design activity.

IV. Conclusion

In this paper, we attempted to provide a deeper understanding of perspectives of design activity across two fields that engage in design to identify spaces for shared language or necessary abstractions. We recognize that these are two of many perspectives on design in engineering and industrial design, and are not meant to be a blanket description of design activity in both fields. It is our intention, however, to provide these perspectives in rich detail so that the reader may transfer their learnings about the connections and distinctions to their own contexts and practices.

Our intent also is not to place a higher value to either perspective, in fact both approaches have worth and present dilemmas. As Lawson and Dorst [1] warn, being overly analytical leads to unnecessarily limitations, while being overly creative "can launch a journey into nothingness" (p. 28). Educators who teach across engineering and design should acknowledge the difference in how students from both fields view design problems and judge the effectiveness design solutions, while leveraging the common elements of design activity to find curricular spaces where students can collaborate and share knowledge. Further empirical study on the problem-solving approaches of engineers and designers, to create a process model and taxonomy of design-focused problem solving, would lead to a greater understanding of design activity in interdisciplinary projects and research. Future studies may also reveal a need for additional socio-technical dimensions, the framing of possible collaborations on projects, and better understanding of views for division of responsibilities in order to develop a better approach to evaluate perspectives on the diverging criteria and values systems in the two fields.

In conclusion, there are three axes in the general area of technological literacy: knowledge, capabilities, and critical thinking [5]; engineering, design, and all technological-related fields can be mapped on these axes. We also need another dimension, socio-technical literacy, to improve the thematic nature of learning and design in these areas [6]. As educators, we believe that interdisciplinary connections strengthen students' social-technical skills, encouraging students to work together to use their distinctive disciplinary knowledge to solve common problems. Focusing on design activity is one way to bridge the disciplinary divide between engineering and design fields [7][8][9]. Our first step, therefore, is to find a shared language around perspectives and practices while valuing the distinctiveness of each approach.

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