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Integrating Social Issues into Design Theory*

WILLIAM H. WOOD
Department of Mechanical Engineering, University of Maryland, Baltimore County, Baltimore MD 21250, USA. E-mail: bwood@umbc.edu

A reductionist approach to inquiry in the field of design theory and methodology leads naturally to examination of the lone designer and is the foundation for the development of theories for design. Even in this simplified setting, the two 'heads' of design research emerge: describing what effective designers actually do vs. prescribing what they should do. Without partnership between the two sides there is little hope that developed theories will be applied. Another bifurcation in design occurs between the two primary cognitive activities: generating design options vs. selecting among them. These activities are interleaved; theories that isolate one from the other cannot grasp the real nature of design. This paper examines existing paths toward building design theories that extend beyond the lone designer into groups of interacting designers and further into design situated in a social environment. This analysis points to the need to develop tools that anchor successful real-world design strategies into more formal foundations, helping design teams interact in ways that are both effective and natural.

INTRODUCTION

HUBKA AND EDER [1] are not alone in suggesting that research in design theory should be primarily directed at establishing a science of design. This begs the question: is design a natural science or a social science? This has resulted in somewhat of a schism in design research: *prescriptive research* is concerned with developing formal theories for how design should be done, whereas *descriptive research* takes an ethnographic approach to determine the important processes in design through observation. Both sides have primarily adopted a reductionist approach—isolating the individual designer as the basic unit of study in the design process. This suggests that design teams can be modeled simply by replicating the individual model and that the interactions between design teams and society can be modeled by replicating individual designer/customer pairs.

This paper is structured as a comparison of prescriptive and descriptive findings at three different aggregation levels:

- the individual designer;
- the design team;
- interacting design teams/enterprises.

In the end, this comparison will yield findings that help to direct effort in design theory research toward embracing design as a social activity both in terms of the interactions among its practitioners and their relationship to customers and society in general.

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THE INDIVIDUAL DESIGNER

This scenario typically begins with an individual who is charged with conceiving a system which fills the needs of a given customer. Descriptive research generally focuses on circumscribed problems where significant headway can be made in a short time period. Prescriptive research often is mute regarding the size of the design team, so we will limit consideration to methods that do not explicitly deal with either decomposition or modeling multiple objectives.

Descriptive

Ullman *et al.* [2] uncover a set of generic actions that designers take throughout the design process:

- assimilate
- specify
- plan
- document
- repair
- verify.

They also find that the balance among these actions changes as the design progresses from conceptual to layout to detail design, but assimilate/plan/specify, which yields to document/repair/verify, are sprinkled throughout.

In another take on the same design data, McGinnis and Ullman [3] describe the additional processes of feature definition and abstraction. These are concerned largely with the development of constraints among interacting components of the design—creation of a design model.

Prescriptive

The prescriptive method that is most closely associated with descriptive work is quality functional deployment and the associated QFD diagram (i.e., the 'house' of quality—HoQ [4]). The HoQ serves two main purposes: first it attempts to translate subjective customer needs into objective engineering quantities, second it strives to represent the design space by identifying dependencies among these quantities. Additional checks on the translation are supported. While the HoQ can be used to set design targets, its primary purpose is to help structure the evaluation space in the context of the design space.

While the HoQ delivers on the descriptive importance of structuring the design problem, most other prescriptive methods have tended to focus on rationalizing the search/selection process. Building on optimization methods, the search takes place largely within a design space that can be fully characterized by a design vector. Mathematical constraints and objectives focus on search. Design theory research has attempted to move this framework earlier in the design process, adding 'uncertainty' to model the ambiguity that pervades early design.

One thread has adopted a probabilistic framework, drawing from prescriptive research in economics in applying decision, utility, and information value theories to design [5–9]. In echoing Einstein's famous quote 'God doesn't play dice with the universe', Antonsson and Otto [10] express a distaste for the general notion of probabilistic design, substituting fuzzy logic for management of uncertainty in their Method of Imprecision. This mechanical change belies a fundamental posit: that any design evaluation must include a property of annihilation wherein violation of a constraint causes the invalidation of a design. Together, these techniques focus on bringing rationality to the decision aspects of design.

Prescriptive design techniques that do not focus on the decision process include axiomatic design and TRIZ. Axiomatic design [11] focuses on the structure of a design and its resulting model. Design is broken into functional requirements and design parameters (parallel to the above constraint/objective and design vector). Axiomatic design prescribes that the best designs are uncoupled (i.e., each functional requirement is addressed by a single design parameter) or decoupled (i.e., each functional requirement can be addressed independently). Again, uncertainty is the motivation behind the prescription—requirements change, so designs must be readily adaptable.

Other than simple reorganization steps for decoupling, axiomatic design prescribes a metric, not a method. TRIZ [12] addresses methodology, providing a framework to focus design concept generation. Recognizing that design improvement is often thwarted by conflicting constraints, TRIZ applies an extensive survey of technical patents to produce a mapping from conflict to potential resolution. Resolutions vary from general concepts to specific techniques for resolving design roadblocks.

Observations

On the descriptive side, designers spend a large amount of time structuring the design problem, understanding the customer needs, generating a set of constraints, identifying potential solutions, and narrowing down the solution set. The actual ideation process is still something of a mystery. The prescriptive side has focused on design problems that are already well-structured, but does not require certainty in modeling design behavior, constraints, or objectives. Decision-based design does tend to require certainty on the solution side of the equation. This is an artifact of decision theory itself, where options are treated as exogenous to the decision. In design, however, generating options is very much a part of the process. Case-based reasoning in the form of TRIZ can help generate design options indirectly, but no technical solution is likely to fully address the ideation process.

DESIGN TEAMS

Descriptive

Bucciarelli finds similarities to feature definition and abstraction in what he describes as 'object worlds'. The use is similar—just as individual designers use abstraction to compartmentalize knowledge, design teams use abstraction in object worlds as a means of data hiding. Each discipline creates its own view of components of the design; these views must at some point be merged into a coherent model. The origin of constraints in design comes out in a team environment. While the laws of physics provide many constraints on the behavior of components of the design, most are social constructs to govern interfaces both between interacting subsystems and between the design and its (physical/social) environment. Abstraction at the individual level leads to the merging of 'object worlds' as a single design representation forged from the varied abstractions within the design team.

The process of design is one of negotiation and mutual understanding. Kunz and Rittel [13] describe a similar process in which negotiation helps to shape both the design and its evaluation in parallel. Communication and information is at the core of both of these descriptions of design teams activity. As a result, many corporations have reorganized themselves around the concept of product-oriented collocated multidisciplinary teams.

Sobek *et al.* [14–16], in describing Toyota's process, offer a different take on team-based design. Communication here is highly structured, again toward resolving the various viewpoints of different stakeholders. However, rather than relying on the team to arrive at the best compromise, Toyota relies on a lead engineer. Rather than specific targets, each designer is given a range of specification that must be satisfied. In addition to performance specifications, each designer is also expected to satisfy extensive design checklists to ensure basic design feasibility (mainly from a production standpoint).

Satisfying ranges of design requirements might call for one highly variable design or several specialized designs. The lead engineer manages negotiations among various stakeholders (e.g., styling, structural, manufacturing, systems, etc.) by successively narrowing the design specification ranges. It is significant that some specifications are never narrowed to a single point (e.g., the total length of the car may never be specified completely). This methodology encourages design exploration and allows the consideration of concrete examples for trading performance among the stakeholders.

Prescriptive

Again decision processes dominate the prescriptive side of design research at the team level. Rather than a single objective, team-based design introduces multiple objectives corresponding to the different priorities of each discipline involved in the design process. In combination with the uncertainty already introduced into the problem, the aggregation of multiple objectives poses significant problems. Multi-attribute utility theory aggregates the individual utilities of each stakeholder, generally either through weighted sum or a multiplicative form that dovetails easily into the process of eliciting utilities. Scott and Antonsson [17] build on the Method of Imprecision, suggesting that commensurability among objectives is the primary consideration in aggregation. They provide a framework that can establish not only weights but commensurability among design objectives [18] that employs indifference lotteries similar to those used for garnering utility information.

Mistree *et al.* [19], take a different course in aggregating competing objectives. Rather than generate a single objective, they apply a preemptive goal-programming framework in which negotiation among stakeholders focuses on trading off aspiration levels (minimum performance levels) among the multiple objectives. Unlike the above methods in which negotiation takes place in the evaluations space, here negotiation is grounded in the design space. Each iteration in the evaluation space is accompanied by a search in the design space. 'Extra' design space, revealed in over-achieving aspiration, can be used to raise expectations; failure to achieve an aspiration level feeds a negotiation to lower aspiration for some other objective(s).

Ward *et al.* [20], attempt to formalize the Toyota's 'set-based' design process using interval calculus. Toyota's requirement ranges are modeled as the endpoints of intervals. They develop design-specific operations that reflect the need to: propagate requirement uncertainty back into the design space, propagate the resulting design uncertainty into other requirement spaces, find designs that satisfy a range of requirements, and find designs whose performance falls within a range. In the end, Finch and Ward apply predicate calculus to describe sets and relationships among them [21].

Observations

Again, prescriptive practice focuses mainly on the selection problem. The importance of negotiation found in descriptive research is born out in the prescriptive methods for aggregating evaluation functions. The dichotomy between exploring design space versus exploring evaluation space comes out at the team level. Toyota's methods, set-based design, and goal programming all focus on the design space but lack true formality. Multi-attribute utility theory and the method of imprecision provide the desired formality for prescriptive theories but are only indirectly involved in the design space. It is interesting that, while at the level of team design communication becomes of vital importance, that the strongest theories can communicate on only one half of the design equation.

DESIGN ENTERPRISES

Descriptive

Toyota's methods come to light once again on the enterprise level. So-called 'lean production', pioneered by Toyota, is slowly displacing mass production as the most effective means of supplying technical goods to society. The overall philosophy is one of cooperation. While the Toyota supply chain is large and complicated, supply contracts are designed to foster cooperation rather than competition [22]. To ensure equitable treatment within the organization, a high level of cross-ownership within the supply chain places success of the group over success of the individual company. The social construction of the enterprise even reaches out to the customer base: extensive interviews relay the voice of the customer to feed information to the design process; customers are prompted to consume goods at rates that help balance factory load; customers are embraced within the 'family' of the enterprise as full partners in its success.

Prescriptive

Prescriptive methods tend to focus on one of two levels: interactions within the enterprise/supply chain and interactions between competing enterprises and the customer base. Competition within the supply chain is frequently a hallmark of mass production. The primary organization typically performs almost all of the design functions, manufactures a large portion of the designed components, and assembles/integrates components into a product. A subset of components is let out for bids on a competitive basis. This model presents a fairly straightforward path for the extension of decision-based design: game theory. This adds an additional layer of complication; uncertainty about actions taken by the competition must be included into the decision process. Where contracts are awarded to the lowest bidder, there is a large incentive to cut costs. However, as Kahn and Murnighan point out, one of the large imperfections in game theory involves the horizon over which the game is played [23]. Strategies emerge to take advantage of imperfections in the game. For example, the cost of a component in competitive-bid mass production often increases over time as the supplier, who might initially lose money on each component shipped, takes advantage of design changes to eventually turn a profit. Game theoretic techniques have difficulty modeling short horizon games—cooperation for the greater good is the best strategy for an infinite horizon in the classic prisoner's dilemma; competition is optimal for a fixed horizon.

Game theory can also be applied to competition between design enterprises. Increasingly, however, direct competition is de-emphasized in favor of marketing techniques used to carve up the consumer space into niches that can be exploited. Niche marketing and mass customization are the bases for emerging prescriptive methods in product family development [24, 25] and design for variety [26]. These methodologies broaden the scope of design from the development of a single product to a set of products that cover varied customer needs. Again, this can be treated as a decision-based design process once options for product families have been defined. The family that maximizes profit by covering the largest market need at the lowest cost should be chosen.

This need to deal with a heterogeneous customer space has prompted Hazelrigg [27] to invoke Arrow's Impossibility Theorem to recast decision-based design away from characterizing and aggregating preferences toward the maximization of profit in terms of customer demand and time value of money. Scott and Antonsson [28] argue that this drastic move away from the roots of design evaluation in terms of technical performance and features is not necessary. Simply designing a product does not force a change in a consumer's preference structure (as it would, say in a political election where only one choice can prevail), it offers a choice to the consumer. They emphasize, again, that the aggregation of multiple design objectives must remain the focus of decision-based design.

Observations

At the enterprise level, the social aspects of design really come to the fore. Large industries fostered by free market concepts of competition are being toppled by cooperation-oriented enterprises. This strikes at the heart of the distinction between design and decision-making. A decision-maker is presented with a set of options from which to choose: a game-player with a set of rules. Each works within what is given to achieve goals. A designer confronted with the same situation responds not simply by selecting among options but by expanding the space of options. Lean production represents a designer's response to mass production—work within the system, but also consider changing the system.

SYNTHESIS

Design theory has evolved in a sort of means-ends analysis. Starting from foundations in optimization, prescriptive design has embraced uncertainty and multiple objectives as a way to move upstream into the more ambiguous aspects of the design process. Descriptive design starts at the other end of the spectrum, with a designer situated in the 'fuzzy' front end of the design process trying to bring structure to the design space and consistency to the evaluation space. The main artifact of the optimization underpinnings in prescriptive design is the neglect of the design space. In optimization, generating design options is trivial: just change the design vector. Constraints can complicate design option generation, but not beyond that which a computer can easily handle. Another artifact of optimization methodology is the partitioning of the design evaluation model into constraints and objectives. This distinction is important for computer implementation but less important to the actual design: descriptive research demonstrates that immutable physical laws must be blended with socioeconomic considerations in the evaluation model. It is not clear yet whether the means-ends analysis is succeeding. The two sides have clearly not met in the middle—the debate over the theoretical weaknesses of the HoQ illustrate the rocky middle ground yet to be traversed in bringing the two sides together.

The two sides have made much better progress at the team level. Descriptive research focuses on the negotiation of multiple competing concerns; the prescriptive side takes up issues of aggregating multiple objectives. The language of the two sides differs, descriptive work suggesting that communication is the main issue while prescriptions focus on the functional form of an aggregate objective. To the extent that tools for determining this form provide touchstones for negotiation, the two sides come together. However, because prescriptive methods focus mainly on the evaluation space, negotiations centered here cannot be complete—they must eventually account for issues that arise in the design space.

The enterprise level is perhaps the most interesting, revealing how small differences at one scale can be exaggerated at the next. While negotiation is at the core of both descriptive and prescriptive research at the team level, as these teams are expanded into large organizations and across organizational boundaries the two sides diverge sharply. Descriptive research carries through the cooperation/collaboration spirit of the intermediate level, finding that lean production techniques emphasizing coordination and collaboration significantly outperform traditional mass production. Competitive aspects that arise from aggregating multiple objectives in a design team are magnified as those objectives transcend organizational boundaries. While at the team level the general assumption is that the group members will subordinate their own needs for the common good, at the supply chain level game theory reveals how cutthroat and competitive extramural relationships can be.

CONCLUSIONS

What are we to draw from this discussion? First, that design theory has far to go toward incorporate social issues, not only from the standpoint of helping designers to navigate the complex process of understanding and integrating the needs of society into a structured design framework but also with respect to how individuals and organizations collaborate and cooperate. Enhancing communication among stakeholders in the negotiation process is vital to improving design. To date formal design theories have focused on design evaluation, framing collaboration as the process of aggregating multiple objectives. This captures only one side of the equation. Designers are charged not only with evaluating a set of options but with generating that set as well. Negotiation must account for the difficulty of generating design solutions. Wood [29] suggests that generic measures of design freedom be introduced into the negotiation process. This captures the spirit of Toyota's powerful lead engineer by assessing not only the degree of satisfaction that a particular set of requirements brings but also the degree to which they constrain the set of options. Designers must preserve ambiguity (I believe Stanford's Larry Liefer was the first to articulate this phrase) throughout the design process. This ambiguity must be as carefully parceled out among team members as current theories apportion performance.

As a parting note, it is interesting that in redesigning the design process, Toyota has revolutionized modern industry. Designers, confronted with a meager set of options, generate new ones. While it is important to build on the solid theoretical foundations of decision-making under uncertainty, we must not forget that design is fundamentally different. Theories that do not address activity in the design space are only partial theories of design. Likewise, theories that cast collaboration as more competition than coordination fail to account for the power of social constructions in the design process.

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William Wood is currently on the faculty in the Department of Mechanical Engineering at the University of Maryland, Baltimore County. His research interests include design theory and methodology, the role of information in the design process, design for manufacture, and design education. His teaching interests revolve around delivering an effective capstone design course that balances theory and practice in a consumer and society-conscious setting. Dr. Wood received his Ph.D. from the University of California at Berkeley after receiving BS and MS degrees at Duke University.