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A HYBRID NEGOTIATION-AUCTION MECHANISM FOR DESIGN SOURCING

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ABSTRACT
The source of innovation is increasingly coming from outside instead of from within, which makes it an imperative for companies to effectively source designs. However, design sourcing involves complex and coupled decisions in both engineering and economic domains due to information asymmetry, information stickiness, and conflicting incentives. This paper models design sourcing as a *contracting* problem with an embedded *collaborative design* problem. A hybrid negotiation-auction mechanism is proposed to reconcile the conflict between competition and collaboration in information sharing and problem solving. The mechanism is proved to be socially efficient and it provides necessary flexibility and right incentives for design innovation. With mathematical formulation, the mechanism can serve as a foundation to develop information systems for design sourcing.

Keywords: sourcing, contracting, negotiation, auction.

1 INTRODUCTION
According to a study by Engardio et al. on BusinessWeek in 2005 [1], 20% of design for mobile phones, 30% for digital cameras, 65% for notebook PCs, and 70% for PDAs are outsourced by original equipment manufacturers to suppliers or specialized design firms. The trend towards design outsourcing is not limited to electronics but is spreading to other industries like commercial airplanes, as showcased by Boeing's revolutionary development of Boeing787 [2]. In the meanwhile, companies like P&G [3] and 3M [4] are insourcing design innovations from suppliers, customers, university labs, and online communities. Whether it is outsourcing or insourcing, a new paradigm of design management is taking shape, in which the source of innovation spreads beyond traditional organizational boundaries [5] and design is carried out collaboratively on a mass scale [6]. To keep up with the pace of innovation, companies need to source design ideas and/or solutions from outside to complement, if not replace, their in-house design operations.

However, unlike products or manufacturing, design is essentially a type of service with high density of knowledge content. As design is essentially about creating something new, it is nearly impossible for a buyer to precisely specify design requirements, for a seller to accurately articulate design capabilities, or for a third-party (e.g. a court) to unambiguously verify design quality [7]. As summarized by Von Hippel, design is about innovative problem solving that requires integration of *need information* and *solution information*, which, however, are usually distributed asymmetrically with users (buyers) and manufacturers (sellers) respectively, and both of which are *'sticky'* in the sense that they are difficult to be extracted, transferred, or used in a different location [5]. Furthermore, as in any transaction, buyers and sellers of design are not fully aligned in their interests. Consequently, design sourcing is a challenging task both technically and contractually. Reaching an agreement over design sourcing is often an iterative and lengthy process with laborious back-and-forth negotiations.

The inefficiency in transaction limits the scope of design sourcing and prevents companies from tapping into external sources of innovation. In this regard, this paper aims to develop an efficient mechanism for design sourcing that can reduce the cost of transaction while provide the right incentives for design innovation. The rest of the paper is organized as the following. Section 2 presents a decision model of design sourcing. Section 3 reviews general sourcing mechanisms and discusses their performances for design sourcing. Section 4 presents a hybrid negotiation-auction mechanism, and Section 5 discusses its performance and applicability for design sourcing.

2 DECISION MODELING IN DESIGN SOURCING

Design sourcing in practice involves many decisions and activities within complex business contexts. For simplicity of illustration, this paper considers a general sourcing scenario, in which a customer selects a designer out of multiple candidates to fulfill a specific design task. This study focuses on the contracting stage in design sourcing. A mathematical model is constructed to capture the essential decisions in design sourcing and the associated incentive and information structure.

2.1 Decisions

The decisions involved in design sourcing can be generally categorized into engineering decisions (e.g. requirements, specifications, lead time, etc) and economic decisions (e.g. price, payment schedule, warranty, etc.). Engineering decisions can be characterized as a *collaborative design (co-design)* problem as the customer and a designer need to collectively search for a mutually satisfactory design solution. Economic decisions can be characterized as a *contracting* problem as the customer and a designer need to reach an agreement over the terms of transaction. Thus, design sourcing can be conceptualized as a *contracting* problem with an embedded *co-design* problem. Without loss of generality, this study selects specification (s) and price (p) to represent decisions in engineering and economic domains, respectively. The customer's and a designer's decisions in design sourcing can be modeled as two coupled mathematical programming problems that seek an agreement on (s, p), which represents a sourcing contract (Figure 1).

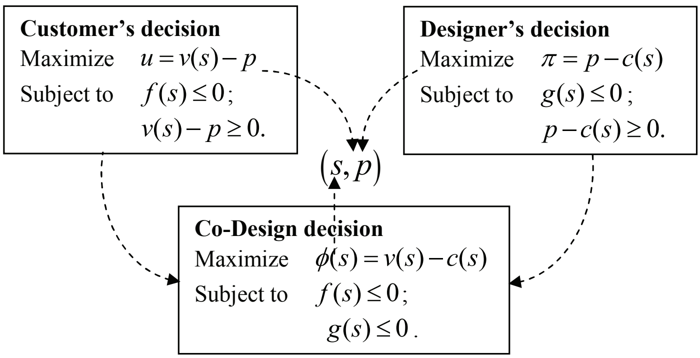

Figure 1, Decision Modeling in Design Sourcing

2.2 Information

The customer and designers are endowed with asymmetric information. Customers have better *need information* because they have better understanding of local environment and intended use of the design; designers have better *solution information* because of their technical expertise [5]. As in any buyer-seller relationship, customers and designers have asymmetric information concerning the value and cost of a design. This asymmetric information structure is captured in the decision model as illustrated in Figure 1. The customer's design requirements and a designer's solution space are modeled with inequality constraints $f(s) \le 0$ and $g(s) \le 0$, respectively. The customer's maximum willingness to pay and a designer's total cost to deliver a design solution are represented by value function $v(s)$ and cost function $c(s)$, respectively. Functions $v(s)$ and $f(s)$ capture the customer's need information, while $c(s)$ and $g(s)$ capture a designer's solution information. Need information and solution information are private to the customer and a designer, respectively.

2.3 Incentives

The objectives of the customer and a designer in design sourcing can be generally taken as to seek a contract that maximizes utility (u) and profit (π), respectively. Both u and π are assumed as quasi-linear functions of s and p [8]. Individual rationality is ensured with constraints $v(s) - p \ge 0$ and $p - c(s) \ge 0$. Customers and designers share common interests in design as s is concerned, as effective integration of need information and solution information is necessary to indentify innovative design solutions. However, they have mutually opposed interests in contracting as p is concerned. As decisions on s and p are coupled, there exists conflicting incentives between collaboration and competition. Consequently, there is dilemma in design sourcing as co-design requires truthful sharing of need information and solution information while competitive contracting entices strategic withholding or misrepresentation of private value and cost information.

3 GENERAL SOURCING MECHANISMS

A sourcing mechanism is the procedure and rules that a buyer utilizes to select and contract with a supplier to fulfill a certain task. There has been a growing stream of research on economic mechanism design for procurement of complex products and services. The large number of mechanisms reported in literature can be generally categorized into either negotiation-based or auction-based. This section discusses their general properties and performances.

3.1 Negotiation-Based Mechanisms

Negotiations are bi-lateral mechanisms that have flexible procedures and rules. It is arguably the most widely practiced mechanism for trading in general. The bilateral interaction during negotiation is essentially a process of joint decision making with partial information exchange. With a highly flexible structure, negotiation-based mechanisms generally have a large 'bandwidth' of communication over multiple issues and have a large tolerance for ambiguities. Multiple issues imply higher degree of freedom, as different parties usually have different preference profiles and mutually beneficial agreements could be identified through a process of take-and-give [9]. Such properties are desirable for co-design as design subjects are often multi-attribute in nature and customers (designers) are often unable to accurately articulate needs (capabilities).

Although negotiation is flexible enough to handle complexity and ambiguity in design sourcing, it is an inherently inefficient mechanism for transaction. Raiffa et al. point out that *"value creation is usually inextricably linked to value claiming and the tactics used to create a larger pie may conflict with tactics designed to claim a larger slice of the pie*", creating a so-called "negotiator's dilemma" [9]. Myerson and Satterthwaite have analytically proved "*the general impossibility of ex post efficiency of bargaining without outside subsidies*" [10]. In other words, there is always possibility that negotiators may fail to reach an agreement, even though mutually beneficial solutions are available. The root cause of such inefficiency lies in lack of incentives for truth-telling in negotiation.

3.2 Auction-Based Mechanisms

Auctions are multi-lateral mechanisms that have fixed procedures and rules. Auctions used for sourcing are also called reverse auctions. When the product or service is standard, reverse auctions are efficient in price discovery by forcing suppliers to reveal private cost information through competitive bidding [11]. Such properties are desirable as price is concerned, but the rigid procedures and rules of a reverse auction make it ineffective in handling multiple attributes and ambiguous information. As design is often highly differentiated and uncertain, bidding solely on price could result in awarding the contract to the lowest bidder but with poorest quality.

One approach to mitigate this problem is to establish a "quality floor" for non-price attributes and only qualified suppliers are selected to bid on price. Although a price auction with a quality floor reduces bidding to a single dimension thus reduces complexity, it requires the customer be able to accurately articulate design requirements. Ambiguous requirements may necessitate customer-initiated design changes and contract re-negotiations, which could result in extra costs and additional charges from suppliers. Furthermore, as qualified suppliers are treated as homogeneous, high-quality suppliers do not have incentives to participate and participating suppliers do not have incentives to innovate.

Another approach to adopt reverse auction for design sourcing is to define a score function, which converts both price and non-price factors into a single score (i.e. a 'virtual currency') to represent the overall value of a bid to the customer. As competition is not restricted to price, score auctions are more efficient in contract allocation and give better incentives for designers to innovate. However, it requires the customer to be able to articulate the performance metrics to evaluate design solutions *ex ante*, which, however, is often difficult as design solutions are often hard to predict.

4 A HYBRID NEGOTIATION-AUCTION MECHANISM

Negotiation-based mechanisms are effective in supporting co-design, but lack of incentives for truth telling makes them inefficient for transaction. In contrast, auction-based mechanisms are efficient in price discovery and contract allocation, but difficulties in establishing a design quality floor and evaluation metrics make them difficult to implement. Thus, neither negotiation nor auction alone is sufficient to support both co-design and contracting in design sourcing. The rationale of mechanism design in this research is to combine the advantages of negotiation and auction in a hybrid mechanism.

4.1 Mechanism Procedure

Figure 2 illustrates the procedure of the proposed mechanism. The procedure starts with the customer sending out requirements to candidate designers requesting design proposals. Each interested designer responds with a design solution. The customer evaluates each solution and assigns a bidding credit based on the solution's value premium. A designer then decides if he is satisfied with the assigned bidding credit. If not, the designer can negotiate upon requirements and propose a different solution. The process then iterates until the designer either accepts the bidding credit and proceeds to the auction stage or rejects the bidding credit and exits without any transaction. The auction is organized as a standard reverse English auction [11], in which designers bid openly and incrementally lower on price (with design specifications being fixed). The lowest-price bidder will be awarded the contract and receive his bid price plus bidding credit as the final payment. The bid winner is contractually obligated to deliver a final design solution as specified. A losing designer neither makes nor receives any payment.

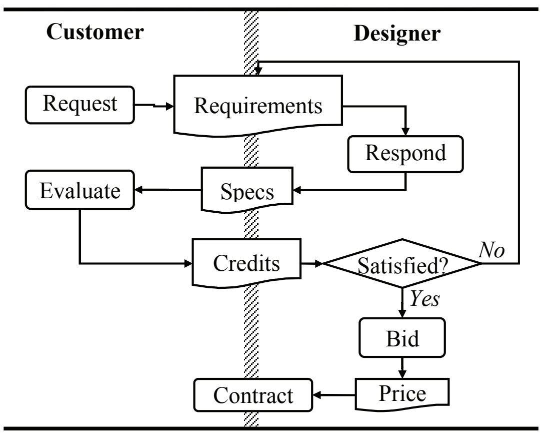

Figure 2, A Hybrid Negotiation-Auction Mechanism for Design Sourcing

From a procedural point of view, the proposed mechanism differs from a negotiation-based mechanism by appending a reverse English auction for price determination and contract allocation; it differs from a price auction with quality floor by allowing design requirements to be negotiable and differentiated; and it differs from a score auction by postponing solution valuation from announcing a score function *ex ante* to assigning bid credits *ex post*. The implications of these differences in terms of mechanism applicability will be discussed in Section 6.

4.2 Assigning Bidding Credits

Assigning bidding credits is a pivotal stage in the proposed mechanism. As designers usually have heterogeneous capabilities, design solutions are likely to be different. Value differences among these solutions, if not properly recognized, would discourage designers from innovation. The use of bidding credits is an effective tactic to encourage participation and promote competition in asymmetric auctions, in which bidders are distinguishably different [11]. Bidding credits can be taken as a promise of extra payment. In this paper, bidding credit is assigned based on the value premium of a design solution relative to a benchmark solution s_0, which could be an existing design with similar features.

$$b(s) = v(s) - v(s_0) \quad (1)$$

With bidding credits, the customer's utility and a designer's profit are modified respectively:

$$u = v(s) - p - b(s) \tag{2}$$

$$\pi = p - c(s) + b(s) \tag{3}$$

4.1 Mechanism Outcome

From the customer's perspective, bidding credits eliminate the value differences among the solutions from different designers. In other words, bidding credits serve to "commoditize" designers and reduce competition to a single dimension, i.e. price. From a designer's perspective, bidding credits represent a source of extra revenue upon winning the contract. They can be taken as free "coupons" upon entry into the auction, which, however, can only be redeemed by winning upon exit. In this sense, bidding credits lower the actual stakes (costs) for designers to be engaged in competitive bidding.

$$c'(s) = c(s) - b(s) \tag{4}$$

Assuming individual rationality, $c'(s)$ represents a designer's lower bound of price bid. $c'(s)$ can be taken as an aggregate measure of a designer's overall capability, as it takes into account of both the cost and value (premium) of his solution. With change of variables, the customer's and a designer's decisions in the auction stage can be formulated as:

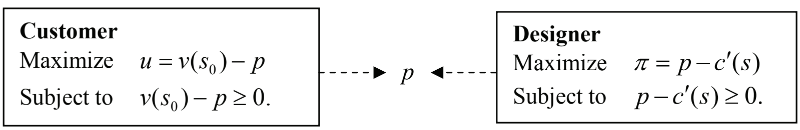

Figure 3, Bidding with Bidding Credits

The above formulation represents a standard reverse English auction with private cost functions. In a reverse English auction, bidders have a dominant strategy to bid down to cost, and the auction concludes with the lowest cost bidder winning and price clearing at the second lowest cost (with a slight deviation due to minimum bid decrement allowed). To derive the outcome of the mechanism, designers participating in auction are indexed by i according to $c'(s)$ in ascending sequence, i.e. $c_1'(s_1) < c_2'(s_2) < \ldots < c_n'(s_n)$, where s_i represents the final specification submitted by designer i. Based on these notations, designer with the first order statistics $c_1'(s_1)$ wins the contract; the clearing price is the second order statistics $c_2'(s_2)$. Thus, the final sourcing contract can be represented as:

$$(s, p) = (s_1, c_2'(s_2)) \tag{5}$$

5 MECHANISM PERFORMANCE

The objective of the mechanism design is to improve the efficiency of design sourcing and provide right incentives for design innovation. Thus, the performance of the proposed hybrid negotiation-auction mechanism is evaluated according to *economic efficiency*, (customer) *utility maximization*, and *incentive compatibility*.

5.1 Economic Efficiency

The efficiency of a mechanism in the economic sense generally consists of two aspects: *social efficiency* and *allocation efficiency*, which are measured respectively by optimality conditions of social surplus (i.e. whether maximum social value is created) and resource allocation (i.e. whether the most competent supplier is selected). The social surplus created with a transaction based on the negotiation-auction mechanism can be derived as:

$$\phi(s) = v(s_1) - c(s_1) = v(s_0) - c_1'(s_1) \tag{6}$$

As s_0 is a constant, s_i is the value-maximizing solution in co-design, and $c_1'(s_1)$ is the minimum out of $\{c_i'(s_i)\}$, social surplus $\phi(s)$ is maximized. Hence, the proposed mechanism is socially efficient. As $c'(s)$ measures a designer's overall design efficiency, selection of designer with lowest overall cost as the bid winner also implies that the mechanism is efficient in allocation.

5.2 Utility Maximization

The customer's realized utility based on the negotiation-auction mechanism can be derived as:

$$u = v(s_1) - c_2'(s_2) - b(s_1) = v(s_0) - c_2'(s_2) \leq v(s_0) - c_1'(s_1) \tag{7}$$

The above result shows that the proposed mechanism is generally not optimal in utility maximization as it fails to extract the entire expected social surplus for the customer. Optimality only holds when designers (at least the top two most competent) have equivalent capabilities, i.e. $c_1'(s_1) = c_2'(s_2)$. In case there is a dominant designer (i.e. $c_1' \ll c_2'$), the designer will capture the lion's share of the surplus. This result suggests that the proposed mechanism is preferably adopted in situations where there is genuine competition among designers. On the other hand, as the proposed mechanism leaves the winning designer a profit that is equal to his efficiency advantage over its strongest competitor, i.e. $c_2'(s_2) - c_1'(s_1)$, this result could be perceived as fair and hence be conducive in promoting healthy competition and cultivating long term collaborative relationship.

5.3 Incentive Compatibility

A mechanism is incentive-compatible if it is a dominant strategy for each self-interested participant to report his private information truthfully [11]. From a designer's perspective, the proposed mechanism gives designers a dominant bidding strategy in the reverse English auction. Knowing that the contract will be allocated to the designer with highest overall design efficiency, designers are motivated to search for a solution that best matches the customer's needs with their capabilities, thus truthfully revealing their solution information in the negotiation stage. From the customer's perspective, however, incentive compatibility depends on the availability of information concerning designers' capabilities and costs. In case designers have similar capabilities and correlated costs, a self-interested customer would strategically handicap the most competent designers when assigning bidding credits. As designers usually have heterogeneous capabilities, information upon designers' costs are generally not available and it is in the best interest of the customer to truthfully assign bidding credits ad reveal private need information. Hence, the proposed mechanism is incentive compatible and effectively reconciles the conflicting incentives between (design) collaboration and (transaction) competition in design sourcing.

6 MODEL EXTENSION AND MECHANISM APPLICABILITY

The decision model illustrated in Figure 1 makes two simplifying assumptions: first, the customer is able to accurately evaluate a design solution *ex post*; second, transaction costs are negligible. This section relaxes these assumptions to consider more general design sourcing scenarios and discusses the consequent impact upon the proposed mechanism. The applicability of the hybrid negotiation-auction mechanism is subsequently discussed in comparison with other mechanisms.

6.1 Uncertainty in Valuation

Postponing valuation of a design until after receiving a solution proposal can significantly reduce, but not eliminate uncertainty. The true value of a design solution may take a long time of actual usage to be accurately assessed. Thus, it would be more general to model $v(s)$ as stochastic instead of deterministic. The proposed mechanism can be adapted to cope with this scenario by assigning bidding credits based on *certainty equivalent*, which is the deterministic value that gives the same utility as a stochastically distributed value stream based on the decision maker's risk attitude [12]. Assuming the value of a design solution follow a normal distribution and the customer be risk averse with a mean-variance utility function, its certainty equivalent can be calculated as:

$$\hat{v}(s) = E[v(s)] - Var[v(s)] / \gamma \tag{8}$$

γ is a positive constant that measures the customer's degree of risk aversion. The equation above indicates that the actual value of a design solution is inversely related to the variance of its value distribution. As negotiation is essentially a process of partial information exchange that gradually removes uncertainty concerning the final solution, it enhances $\hat{v}(s)$ by reducing $Var[v(s)]$. In this regard, the negotiation stage in the proposed mechanism contributes to value creation by means of risk reduction. By substituting $v(s)$ with $\hat{v}(s)$, the stochastic scenario is converted into a deterministic one and the procedure and performance of the proposed mechanism remain intact.

6.2 Transaction Cost

Both negotiating specifications and participating in an auction could be time and resource consuming, resulting in significant transaction cost for both customers and designers. Transaction costs incurred during negotiation and auction in the proposed mechanism are denoted as C_N^c and C_A^c for the customer, C_N^d and C_A^d for a designer, respectively. Negotiation costs (C_N^c and C_N^d) can be taken as variable costs that are proportional to the efforts invested. They create frictions in the search process in co-design, which limit the customer and a designer's ability to identify a global optimal solution. Auction costs (C_A^c and C_A^d) can be taken as a setup cost, which creates entry barriers for auction. From another perspective, C_N^c and C_A^c represent the customer's investment in sourcing while C_N^d and C_A^d represent the "ticket" price for a designer to participate. As only a single designer will be contracted, designers losing out will register a net loss and the customer's efforts invested in dealing with these designers will be "wasted". Anticipating such consequences, the customer need to be very careful in inviting designers and designers may refrain from participating. Consequently, the optimal design may be excluded from the solution space.

In general, transaction cost erodes the customer's utility and compromises the efficiency of the proposed mechanism. As transaction cost can be generally taken as sunk cost, it does not affect assignment of bidding credits. Thus, the basic procedure of the negotiation-auction mechanism remains intact and it can be flexibly "configured" to mitigate the effect of transaction cost by adjusting the relative efforts on negotiation and auction. When the cost of negotiation is significantly higher than that of auction (i.e. $C_N^c + C_N^d \gg C_A^c + C_A^d$), the mechanism can be tilted towards more auction (e.g. by means of reducing iterations in negotiation), and *vice versa*.

6.3 Mechanism Applicability

As discussed in Section 2, design sourcing involves decisions in both engineering and economic domains. The key challenge in the engineering domain lies in information asymmetry and stickiness and the consequent uncertainty concerning design specification. The key challenge in the economic domain lies in the heterogeneity of design solutions and the consequent uncertainty concerning price. Therefore, the applicability of a mechanism for design sourcing can be generally delineated based on its effectiveness in handling these two types of uncertainties (Figure 4).

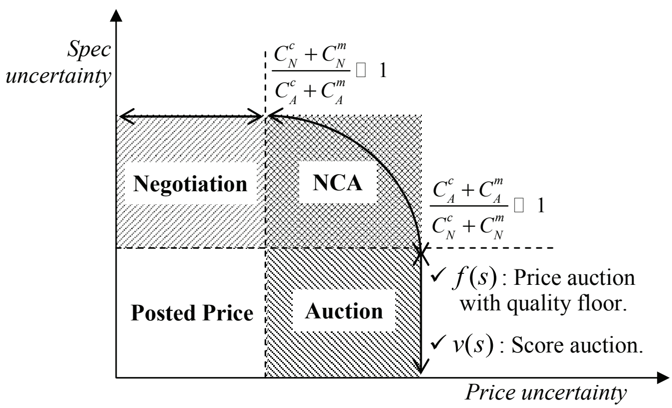

Figure 4, Mechanisms for Design Sourcing

Relatively speaking, when uncertainty on specification is high, negotiation-based mechanisms are preferred due to the necessity for rich information exchange and joint problem solving; when uncertainty on price is high, auction-based mechanisms are preferred because of their efficiency in price discovery and contract allocation. More specifically, if the customer is able to articulate requirements $f(s)$ with high degree of accuracy, a price auction with quality floor is preferred; and if the customer is able to articulate metrics of solution evaluation $v(s)$ with high degree of accuracy, a score auction will be a viable option. Situations where both types of uncertainties are low basically correspond to a degenerate case, when the design task is routine. Situations where both types of uncertainties are high are the primary area of application of the negotiation-auction mechanism. By adjusting the relative weight between negotiation and auction, the mechanism can be configured to cover a large spectrum of situations for design sourcing. It is tilted towards more negotiation (auction) if uncertainty concerning specification (price) and cost of auction (negotiation) is relatively high.

7 CONCLUSION

Design is no longer contained within the walls of a R&D center or even the boundary of a firm but is increasingly dispersed over a large and expanding network of supply chain partners, specialized design firms, research institutes, and even individual consumers. To keep up with the fast pace of innovation, companies are pressured to rationalize their design function by outsourcing existing design activities to outside entities and in the meanwhile insourcing design ideas, resources, and solutions from outside to complement in-house design capabilities. As a result, companies need to find effective and efficient means for design sourcing, which, however, is a challenging task as design sourcing involves coupled and complicated decisions in both engineering and economic domains.

This study proposes a hybrid negotiation-auction mechanism for design sourcing, which separates co-design and contracting into two stages and employs negotiation and auction, respectively. The mechanism is proved to be socially efficient and provides necessary flexibility and right incentives for design innovation. By formalizing decisions involved in design sourcing, the proposed mechanism can serve as a theoretical foundation to develop procurement systems for design. Future research is needed to extend the rather simplified decision model presented in this paper to consider additional factors like design project lead time, risk sharing, and payment schedules, etc. As design and innovation are becoming a main source of competitive advantage, investment in design will continue to grow and design activities will become increasingly specialized and dispersed. This paper contributes to build an efficient marketplace for trading design ideas, resources, and solutions so as to enable an even faster pace of design innovation.

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