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Framing and Tracing Human-Centered Design Teams' Method Selection: An Examination of Decision-Making Strategies

Designers' choices of methods are well known to shape project outcomes. However, questions remain about why design teams select particular methods and how teams' decision-making strategies are influenced by project- and process-based factors. In this mixed-methods study, we analyze novice design teams' decision-making strategies underlying 297 selections of human-centered design methods over the course of three semester-long project-based engineering design courses. We propose a framework grounded in 100+ factors sourced from new product development literature that classifies design teams' method selection strategy as either Agent- (A), Outcome- (O), or Process- (P) driven, with eight further subclassifications. Coding method selections with this framework, we uncover three insights about design team method selection. First, we identify fewer outcomes-based selection strategies across all phases and innovation types. Second, we observe a shift in decision-making strategy from user-focused outcomes in earlier phases to product-based outcomes in later phases. Third, we observe that decision-making strategy produces a greater heterogeneity of method selections as compared to the class average as a whole or project type alone. These findings provide a deeper understanding of designers' method selection behavior and have implications for effective management of design teams, development of automated design support tools to aid design teams, and curation of design method repositories. [DOI: 10.1115/1.4049081]

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1 Introduction

Human-centered design (HCD) is a process used to address a range of problems, from machine design to complex socio-technical challenges [1,2], but is not monolithic: Researchers have cataloged hundreds of distinct design methods that enable HCD, typically organized across phases of Research, Analyze, Ideate, Build, and Communicate [3,4]. Design methods play a key role in HCD because, as Keinonen writes, they help designers formalize attempts "to bridge the emerging conceptions of new design and actual design practice" [5–7]. Design methods are, as Lai et al. write, "a solid first step" but require that practitioners be ready to adapt as they encounter challenges across design phases [8].

Design method selection can shape outcomes across all phases of the design process [9–12], making method selection a crucial aspect of successful design work. Recent scholarship has explored how to best support designers as they select methods, as effective support of designers' design decisions could have a high impact on project outcomes. However, significant questions remain about why design teams select particular methods and how teams' decision-making strategies are influenced by project- and process-based factors.

To explore this, we investigated the following research questions in this work:

- *R1*. How does the prevalence of decision-making strategies used by design teams differ across the *design phase*?
- *R2*. How does the prevalence of decision-making strategies used by design teams differ across *innovation types?*
- *R3*. What elements of the design team's decision-making strategy drive teams' selections of methods?
- *R4*. What is the relative influence of decision-making strategy and innovation type on a design team's selection of methods?

In this paper, we first review related work in design methods and decision making that motivate our study (Sec. 2). We then describe the framework we developed to describe team decision-making strategy (Sec. 3) and introduce research methods (Sec. 4). In Sec. 5, we describe four key results from our work that address our research questions above and proceed to discuss their implications for design practice, design team leaders, and automated design support tools (Sec. 6).

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2 Related Work

In this section, we review related work on identifying design methods and their selection by design teams. We also briefly review work on design team decision making.

2.1 Design Methods, Method Selection, and Selection Support. Since their formalization at the seminal *Conference on Design Methods* more than 50 years ago [13], design methods have become central to design research [14]. In practice, professionals search for design methods based on the expected outcome and rely on personal contacts to explore new methods [12]. While many design methods are newly proposed to support designers, transferring methods to design practice beyond research has proved challenging [15–19]. Several efforts have emerged to catalog methods in a practitioner-friendly format, ranging from industry initiatives such as IDEO's Design Kit (formerly HCD Connect) [20] to the *TheDesignExchange.org* [3,4]. *TheDesignExchange* is the largest open-source repository of design methods and has been built to support design practitioners to explore and implement methods in their practice, as well as share results as case studies to the public [4].

Studies of how such compendia of methods are used revealed patterns in designers' selections of methods. Analyzing data from an IDEO's HCD Connect platform, Fuge and Agogino discovered that designers use research-phase methods more frequently, with the individual interview being the most popular method out of 39 total methods [21]. Fuge and Agogino also described which methods are typically applied together, both within the design phase and beyond it. In another work, Fuge and Agogino explored how design method selections correlated to the topic of a design project—e.g., agriculture or community development—finding several methods uniquely tied to design project topic [22].

Building on understanding what methods designers select, researchers have explored how to *help* designers navigate the design process. A range of stimuli and support tools have been proposed from automatic analogical reasoning support [23] to cards to facilitate creativity in designing for cybersecurity [24]. Among support tools, automated tools to help designers are of particular interest. Fuge et al. developed a machine learning-based method selection tool to suggest methods to designers, discovering that knowing how often methods are used together creates more effective suggestions than methods suggestions based on project content alone [25]. Haider et al. reported an approach to utilize case studies in order to suggest design methods [26]. In examining a classic engineering design problem, truss loading, Raina et al. developed a deep learning agent trained on human designers' on-screen behavior in designing trusses to support design decisions [27]. While not explicitly engaged with HCD, Raina et al.'s contribution blended human behavior (e.g., screen behavior) and human action (e.g., truss outputs) to develop design support. Many other studies seek to help designers in real-time by providing adaptive support based on what designers do, such as Goucher-Lambert et al.'s study of real-time adaptive stimuli for ideation [28] and Zabotto et al.'s automated mood board generation system [29].

These contributions show that studies of method selection and designer behavior have focused on *what* designers did in solving design problems—what methods they selected, or what design artifacts they produced in real-time. However, these approaches are often tied to highly specialized problem spaces or environments. In order to create more effective and generalizable automated design support tools, a deeper understanding of *why* designers took particular action is essential. This deeper understanding could enable nuanced adaptive support based on design strategy rather than design activity and thus much more generalizable than support based solely on historical observation of designers' *actions*.

To explore this, Poreh et al. investigated novice designers' rationale in method selection [30]. This research revealed that student teams align their method choices with various contextual characteristics that surround a project, such as socio-technical issues, industry domain, and user base. Yet, selecting appropriate design methods and the accompanying motivation around the method selection across multiple phases of the design process remains an area of uncertainty. Poreh et al. analyzed the first three phases of the design process: Research, Analyze, and Ideate. In this work, we seek to build on Poreh et al.'s research by first developing a framework to describe designers' decision-making strategy in method selection; second, extending the analysis to a formal definition of project type; and third, expanding the scope of analysis to include more teams and later phases of the design process (the Build and Communicate phases).

2.2 Design Team Decision Making. Decision making in design is an essential facet of innovation and problem-solving, with studies exploring its role in fields from naval architecture [31] to strategic business decisions [32]. Design can be represented as a sequence of decisions that result in a designer's desired outcome [33–36], and understanding decision-making is a crucial precursor to establish agent-based or statistical decision support in design [36]. Quantitative and analytic approaches to characterize and support decision making in design have been grounded in game theory [37], goal-oriented inverse design [38], and sensor data-driven support of demand modeling in design decisions [39]. Recent work by Shergadwala et al. quantified how an individual's domain knowledge and problem framing shape information acquisition decisions [40,41].

Among this work, decision-making *strategy*, a "policy, plan, or process heuristic" for sequencing decisions in solving problems as described by Raina et al. [27,33,36], is an important foundation for explaining observed decision-making behavior. While Raina et al. referred explicitly to computational agents, they used the term to describe the transfer of human design strategies to computational agents. While Raina et al.'s research focused on technical engineering design problems, Valencia-Romero and Grogan's recent quantitative and experimental characterization of design decision making using "strategy dynamics" and binaries of fear and greed explored canonical socio-technical problems [42]. Here we adapt the term *decision-making strategy* to explore the policies and factors that motivate teams to make the decisions that they do, with a specific focus on design method selection as the decision investigated. Like Valencia-Romero and Grogan, we are interested in a broad range of design problems. Unique from published work on decision-making strategy in design, we consider HCD projects across phases as outlined previously.

3 Framework Development

3.1 Decision-Making Strategy. In order to describe decision-making strategies, we established a framework to classify distinct strategies emergent in design teams. We established a context model for the framework development process, first listing 100+ context factors described as essential in product design, product innovation, and new product development literature, chosen for their foundational relevance to engineering design. For example, from management scholarship, Kimberly and Evanisko mention *Leadership, Competition, User Age,* and *Size of the Team* [43]. Meanwhile, Balachandra and Friar, in the engineering literature, describe *Market Existence, Technology,* and *Environmental Support* as contextual factors of innovation [44]; further references elicited a range of factors, from *Task Structures* to *Marketing Synergy* [45–57].

Several factors overlapped, despite being titled differently by various scholars. For example, Kimberly and Evanisko, writing in the management literature, describe "organizational variables" that enable decisions related to innovation activities; one of four such organizational variables was the centralization of team authority in decision making on a team [43]. Similarly, Pintrich et al., writing in the education literature, described "authority structures" as a key driver of how a group is able to achieve conceptual change in

Table 1 Decision-making strategy

Code	Subcode	Context
Agent (A)	Individual (A1)	• Personal interest • Intrinsic motivation • Willingness to try • Familiarity • Self-efficacy
	Group (A2)	• Group diversity • Size of the team • Specification of members • Communication • Team centralization
Outcome (O)	User (O1)	• Customer characteristics • User age/location
	Market (O2)	• Market existence/size • Industry factors • Utility value/market type
	Technology (O3)	• Availability of technology • Simple/complex to realize
	Product (O4)	• Product specific • Characteristic/type/use
Process (P)	Resource (P1)	• Type of supervision • Supportive behaviors • Spatial configuration • Fairness climate
	Constraint (P2)	• Deadline/remained time • Rewards • Evaluation • Task complexity

their work [46]. Both Pintrich and Kimberly's work appears aligned in the importance of authority in shaping decision making. In contrast, Shalley and Gilson, describing creativity in complex organizations, captured a similar concept under the theme "team or work group factors," identifying the social context of a team, and specifically its relationship to a manager or leader, as a key sub-category of this theme; however, the authors do not frame this sub-category in terms of "authority" [54]. Three sources indicated that the nature of power and authority in a team was a key driver of decision-making strategy in teams, but each source presented subtleties and different language in their description of it.

To manage this overlap, two researchers with at least two co-authored publications in engineering design theory research clustered the factors using affinity diagramming. This allowed us to find patterns among factors that might appear substantially different but, in terms of decision-making, describe the same concept. While subjective, affinity diagramming has been demonstrated to be an effective tool to organize complex information and identify patterns [58,59]. The affinity diagramming resulted in three higher-categories (Agent, Outcome, and Process) and eight sub-categories (individual agent, team agent, user outcome, market outcome, technical outcome, product outcome, resource-related process, and constraint-related process). This developed into our framework for classifying design team decision-making strategy (Table 1).

To classify design team decisions, we simplified descriptions of each strategy. Below are the final high-level category definitions that were used during the data coding process. Each is divided into subcodes, which in turn are characterized by specific contextual factors. While all subcodes are listed in Table 1, below we expand on the Agent—Individual Characteristics (A1) subcode—to illustrate how the background literature informed the development of codes and subcodes. A similar foundation in the literature was used to develop the constituent characteristics of each subcode.

- *Agent (A)*: If a decision is centered around an Agent, it means that the focus is on the person (A1) or the group of people (A2) who were responding to the decision (e.g., Designer A chose to use laser cutting because they were familiar with the technique). Below, we expand on the A1 subcode.
    - *A1: Individual Subcode*: Aspects or actions of an individual team member were the key to driving team decision-making strategy. Five contextual factors from the literature were determined to drive this subcode. First, *Personal Interest* describes the personal interests that an individual team member brings to the team. Pintrich et al. surfaced this contextual factor, arguing "personal interests … are aspects of a self-generated context that interacts with the task features" and promoting progress towards the task at issue [46].

      Second, *Intrinsic Motivation* describes the personal motivation independent of extrinsic factors (e.g., rewards, grades, recognition) that drives an individual's relationship to a task. Amabile argued "… motivation can be seen in this context as the most important determinant of the difference between what a person can do and what he or she will do. The former is determined by the level of domain-relevant and creativity-relevant skill; the latter is determined by these two in conjunction with an intrinsically motivated state" (author's emphasis) [56].

      Third, *Willingness to try* captures individual-level readiness to take risks and try new approaches, methods, and strategies. As Reiter-Palmon et al. describe, "… support for innovation is seen through norms for innovation, tolerance for risk and failure when innovation is not successful, and *willingness to try new ideas*" (author's emphasis) [57].

      Fourth, *familiarity* describes an individual's level of experience with or knowledge of a particular concept or area. As Shalley and Gilson describe it, summarizing Weisberg, "Experience in a field also can be a necessary component for creative success because an individual needs some level of *familiarity* to perform creative work" [54,60].

      Fifth, *self-efficacy beliefs*, as Pintrich et al. describe it, are "beliefs that refer to students' judgments about their cognitive capabilities to accomplish a specific academic task or obtain specific goal" [46]. We note that self-efficacy continues to be actively studied in the design education research community [61–63].

- *Outcome (O)*: If a decision is centered on an Outcome, it means that the team's decision was motivated by the expected product-use context such as end-user characteristics (O1), market situation (O2), technological advancement (O3), or specific product use (O4) (e.g., team B developed a wireframe because describing the workflow to a user was very important).
- *Process (P)*: If a decision is based on Process, it means that the organizational elements such as positive resources and gain (P1) or constraints (P2) have a strong influence (e.g., team A chose to use laser cutting because the project deadline was in two days).

While this framework does not account for other important factors in decision making, such as team diversity, trust, and conflict [64,65], it focuses explicitly on team rationale and decision-making strategy specific to method selection. Importantly, the framework is also design topic-agnostic and is developed to examine decision-making strategy in a range of types of design projects.

3.2 Classifying Design Team Projects by Innovation Type. Several approaches have been previously proposed to classify design team projects. Lande and Leifer described manufacturing process, assessment tools, products, and HCD products as categories to describe the nature of design team projects [1]. Fuge and Agogino classified HCD for development projects by their focus area, which ranged from community development to energy [22]. Rather than anchor in the topic of a design project, we seek to understand at a more general level the type of *innovation* a team is pursuing as a way to categorize team projects. We rely on a four-level typology proposed by Ceschin and Gaziulusoy [66]: Product innovation, Product-Service innovation, Spatio-Social innovation,

Table 2 Breakdown of participants

Year	No. of teams	No. of students	Demographic information	Class standing and percentage engineering students
3	9	33	• 19 male and 14 female students • 22 international and 11 domestic	• 54% Engineering students • 38% Senior- or Junior-standing
2	6	28	• 15 male and 13 female students • 8 international and 20 domestic	• 25% Engineering students • 70% Senior- or Junior-standing
1	6	27	• 15 male and 12 female students • 13 international and 14 domestic	• 43% Engineering students • 59% Senior- or Junior-standing
Total	21	88		

and Socio-technical System innovation. By categorizing projects by innovation type rather than output or content, we can seek patterns between projects that may differ substantially in application area, artifacts produced, scope and duration of project, and many other levels. Importantly, Ceschin and Gaziulusoy's innovation typology is distinct from underlying decision-making strategy as outlined earlier, allowing us to examine these two factors independently.

4 Methods

In this section, we describe our data collection approach, the novice student design context in which data were collected, and our approach to coding and classifying data. This section outlines our mixed-methods approach to the research: using qualitative methods to classify team decision-making strategy according to the Agent, Outcome, and Process (AOP) framework (Sec. 3) and quantitative methods to ascertain trends and patterns among qualitative data.

4.1 Data Collection. We collected data from three project-based design courses at a large public research university in the United States over a three-year period (2017, 2018, and 2019). A total of 88 students in 21 teams (Table 2) learned and practiced the HCD process in a two-credit six-week intensive format, which corresponded to 30 h total instruction and an expected 60 h of out-of-class work. Students represented a variety of engineering and non-engineering majors. Non-engineering majors represented in the class included business, architecture, cognitive science, and several subdisciplines of the humanities and social sciences. Class standing varied among students, although the course was intended for students of junior- and senior-standing.

Student teams selected their own project topics in response to an open-ended design prompt, which was articulated "Choose a compelling problem you experience in your daily life." Instructors facilitated student team formation around the most popular project topics, determined by survey-based voting, filtered to project topics most appropriate for a HCD approach in the class. Team sizes ranged between three and five individuals.

The class consisted of a one-week introduction followed by a sequence of one week-long modules focusing on each of the five design phases: Research, Analyze, Ideate, Build, and Communicate. Midterm deliverables were a design review and prototype, and final deliverables were an iterated prototype and presentation encapsulating their work. To illustrate the iterative nature of prototypes developed in class, one team, focused on product-level innovation (see Sec. 4.2), developed an automated cable-winding device for workstation cable management. Early prototypes were constructed out of foamcore, then lasercut plywood, and the final, iterated prototype consisted of a lasercut acrylic housing powered by a servomotor. This prototype successfully retracted and released cables on demand.

The students used *TheDesignExchange.org*, a large open-source, online innovation repository of design methods and case studies [3,4], to learn a variety of design methods and case studies to practice in the context of a semester-long design challenge. In each phase, teams selected three design methods from a subselection of methods from *theDesignExchange* and explained their choices in a short-written justification. This selection and explanation formed our research instrument. To enhance team engagement with the exercise, each team's justifications for why they chose their three methods were scored for all participants on a team, giving each member an incentive to participate in method selection and justification. A total of 60 methods from the design exchange were available for design teams to choose from, an average of 12 methods per design phase. Between years, course curriculum and learning materials were consistent. Two instructors, both with similar design practice and academic design research experience in the same design field, instructed various sections of the course.

In 2018, data from the fifth phase (Communicate) was merged in the final report, instead of the separate data set, and thus, discrete data from one of the three years are not available. Collected data were anonymized and incomplete data were removed. A total of 297 team method selections, representing a 100% response rate from teams, and associated explanations formed the data set used for the analysis. The average length of explanation was 77 words (sd = 51).

4.2 Data Analysis. The data sets were reviewed and coded by two design experts with experience in academic design research and industry design practice, with at least five years' experience studying or practicing design process and methods. The reviewers independently examined the data sets. The decision-making strategy framework (Table 1) was used to code team explanations of why a specific method was chosen. One coder evaluated data from years one and two. The second coder recoded 10% segments of the coded data until an acceptable interrater reliability (IRR) of 0.86 between coder one and two was achieved. IRR of at least ≥0.7 was achieved for each of the Agent-, Outcome-, and Process-focused strategies. The second coder coded the year three data set. Table 3 shows examples of student response and its corresponding coding. Team project final and interim deliverables from the three course offerings were reviewed comprehensively and double-coded

Table 3 Representative student response

Category	Student response
Agent (A)	I chose this design because this suits my visual learning from me drawing out my data instead of writing it out. (A1) As a group, we discussed which all methods we had available to us and came to a consensus on using composite characters after light discussion after realizing this was different enough from the other methods in order to not be redundant. (A2)
Outcome (O)	I chose this method because it enables the researcher to identify new opportunities in the market, which is an aspect of this design challenge. (O2) We all agreed that competitive analysis would allow us to similarly explore a wide range in the technology sphere. (O3)
Process (P)	The method is used for rapidly expressing the concepts. Sometimes it is hard for teammates to understand each other's ideas by words, so it is a good idea to use it to communicate the concepts better. (P1) We also thought it would be easy for all members to work on together and only requires affordable materials … it is also an efficient and cost-effective way to collect and organize information about users, goals and tasks. (P2)

Table 4 Innovation type and example projects

Innovation type	No.	Example project description
Product	7	A device to help users keep their valuables safe when enjoying live events
Product-Service	7	A service to help artists and creators keep track of their ideas and continually be inspired
Spatio-Social	7	An augmented reality safety network that utilizes the existing framework of street lamps to increase safety and security through smart navigation
Socio-Technical System	0	—

for classification by Ceschin and Gaziulusoy's innovation typology (Table 4).

Because data on the fifth phase, Communicate, was not separately collected in 2018, we have left this phase out of cohort-wide discrete data analysis (Fig. 3). However, for proportionate data analysis, we do examine the Communicate phase.

4.3 Method Selection Difference Parameter. In order to compare the effect of decision-making strategy and innovation type on method selection, we introduce a metric, the *method selection difference parameter*, which allows us to compare the proportion of a given method's selection by factor (e.g., decision-making strategy) in a given phase with the proportion of a method's selection overall in that phase. This parameter gives us an indication of how different or similar selection patterns within decision-making strategies or innovation types are compared to the overall observed average. By examining differences in factor-based proportions from the overall mean, we establish the method selection difference parameter, $S_{Mod,i,C}$:

$$S_{Mod,i,C} = abs\left(\left(\frac{\sum_{C=1}^{3} N_{Mod,i,C}}{\sum_{i=1}^{M}\sum_{C=1}^{3} N_{Mod,i,C}}\right) - \left(\frac{N_{Mod,i,C}}{\sum_{i=1}^{M} N_{Mod,i,C}}\right)\right) \quad (1)$$

where *Mod* is the design phase, from 1 through 5, corresponding to the Research through Communicate phases; *C* is the factor level, from 1 through 3, representing either agent, process, and outcome or the three innovation types; *N* is the number of times the *i*th method in a phase was selected under a certain factor; and *M* is the number of methods available to be chosen in a certain phase. For example, $S_{1,1,1}$ is the method selection difference parameter for the first method ($i = 1$) of the first phase ($Mod = 1$, Research phase) by the first factor ($C = 1$, corresponding to agent). For example, $S_{1,1,1}$ examines the first method in the first phase (the 1:1 Interview). It measures the difference between the proportion of methods selected in phase 1 using the agent-driven decision-making strategy represented by the 1:1 interview and the proportion of methods selected in phase 1 overall represented by the 1:1 interview.

The method selection difference parameter is a comparison of proportions. Instead of comparing a z-statistic for each individual pairing, we calculate the absolute value difference of the proportions and then perform standard hypothesis testing approaches on the distribution of proportion differences to determine the significance of difference between decision-making strategy and innovation type and the overall average. The magnitude of the method selection difference parameter helps indicate the extent to which given method's selection is sensitive to a given decision-making strategy or innovation type, relative to the overall observed averages in the data. This factor does not allow us to claim significance of data but rather points to differences from the global average.

5 Results

In this section, we consider dynamics of method selection strategy between phases (R1) and examine the relationship between method selection strategy, project type (R2), and the design method selected (R3 and R4).

5.1 R1: Outcomes-Driven Selection Is Less Used Than Other Decision-Making Strategies, Except in the Build Phase. Among overall findings (Table 5), agent- and process-driven method selections were used more than outcomes-driven method selection (Fig. 1(*a*)). A pairwise proportion test revealed significant ($p < 0.05$, Holm-adjusted) differences, with a small effect size according to a Cohen's h test, between A–O (difference = 0.15, $h = 0.33$) and O–P (difference = 0.12, $h = 0.26$) proportions.

Across innovation types (Fig. 1(*b*)), a pairwise proportion test revealed three significant ($p < 0.05$, Holm-adjusted) differences between selections. Across all design process phases (Fig. 1(*c*)), a pairwise proportion test revealed six significant ($p < 0.05$, Holm-adjusted) differences between selections. These results are summarized in Table 6.

These findings indicate that design teams' method selection appears to be driven by organizational (process-driven) and team (agent-driven) factors, rather than factors related to the outcome of the design project, such as the user, technology, market, or product itself. Outcome-driven method selection in phase 3, Ideate, accounted the least number of methods chosen.

5.2 R2: Spatio-Social Innovation Projects Exhibit Unique Distributions of Decision-Making Strategy. Spatio-Social typologies show a different distribution of decision-making strategy from other types, with a large number of methods being chosen for process-driven factors (Table 4 and Fig. 1(*b*)). A closer examination of underlying trends shows that five of seven teams pursuing Spatio-Social innovations exhibit selection behavior indicative of the process-dominated overall trend, while only one team pursuing both Product and Product-Service innovation demonstrated selection behavior led by process factors (Fig. 2). Using a pairwise proportion test, the observed differences between spatio-social teams were found not to be significant ($p > 0.05$, Holm-adjusted), so our analysis of Fig. 2 is descriptive.

We examined three different projects and their corresponding rationale for choosing the 1:1 interview method in phase one. This examination revealed interesting differences in decision-making strategy as shown in Table 7. We note that rationales for method selection differ substantially between methods and teams, even independent of innovation type, and the listed responses are not comprehensively illustrative of method selection behavior observed.

5.3 R3: Outcome-Driven Decision-Making Strategy Demonstrates a Shift Between the Analyze, Ideate, and Build Phases, Largely Caused by a Transition From a User- to Product-Focus in Outcome-Driven Strategy. We traced how teams' decision-making strategies evolve over the course of the design phases studied. The relationship between decision-making strategies chosen in each phase (Fig. 3(*a*)) reveals reduction in outcome-driven method selection between phase 2 and phase 3 but a growth in outcome-driven method selection from phase 3 to phase 4. We emphasize that these data are independent of the methods themselves, as it is focused on method selection strategy only. We also note that this analysis only reveals trends between two contiguous phases and does not distinguish trends beyond that (e.g., it relates team method selection strategies between phases 1 and 2, 2 and 3, or 3 and 4, and not, for example, phases 1 and 3).

Examining specific subcodes of selection strategy, we see that in the phase 1–2 transition (Fig. 3(*b*)), user-focused (subcode O1) and market-focused (subcode O2) strategies account for almost all of the outcomes-driven method selections. The phase 2–3 transition (Fig. 3(*c*)) is characterized by movement between team-focused agent-driven strategy (subcode A2) and gain-focused process-driven strategy (subcode P1), as well as a smaller but important shift from code O1 to codes A2 and P1. The growth of outcome-driven strategy between phase 3 and phase 4 (Fig. 3(*d*)) is driven by a shift from A2 and P1 strategies to product-focused outcome-driven strategy (code O4). Thus, we observe that outcome-driven strategies are used less than agent- and process-driven strategies in design phases up to the build phase. When outcome-driven strategies become prevalent in the build phase, they are driven almost exclusively by an increase in product-focused strategy (O4), as opposed to user-focused strategy, O1, which accounted for most of the outcome-driven strategy in earlier phases. An example of a team working on a Product-Service innovation illustrates this shift from O1 codes in the Analyze phase to O4 in the product phase, shown in Table 8.

This trend in method selection strategy illustrates a pathway of teams' consideration of outcome-oriented method selection and is further evidenced by the specific methods each team chose (Fig. 4). Teams begin phase 2, Analyze, with user-focused outcomes, choosing methods such as Empathy Maps and Customer Journey Mapping. In the transition to phase 3, Ideate, teams de-emphasize user-focused outcomes as they select methods such as Brainstorming and 6-3-5 Brainwriting. In phase 4, Build, teams' method selection strategies have a renewed outcome-driven emphasis but are centered on product-focused outcomes, leading teams to select methods like tangible prototypes and wireframes. In phase 4, O1 codes notably converged on the Experience Prototype method. We expand on the implications of specific methods chosen and strategies employed in Sec. 6.3.

5.4 R4: Method Selection by Decision-Making Strategy Differs More From the Global Average Method Selection Than Method Selection by Project Type. We examined how frequently methods are selected within each module. We compare (1) the proportion of overall methods selected accounted for by a given method with (2) the proportion of agent-, outcome-, or process-specific method selections represented by the given method (Fig. 5) and (3) the proportion of methods selected in Product, Product-Service system, and Spatio-Social innovation projects represented by the method (Fig. 6). For example, the 1:1 Interview was a popular method in Phase 1, accounting for a proportion of 0.19 of all methods selected in Phase 1. Among process-driven methods selected, coded "P," however, the 1:1 Interview was even more popular, accounting for a proportion of 0.286. In contrast, among outcome-driven and agent-driven methods selected, the 1:1 Interview represented proportions of 0.176 and 0.12, respectively, both below the overall average. Considering innovation type among Product, Product-Service, and Spatio-Social innovation types, the 1:1 Interview accounted for proportions of 0.143, 0.190, and 0.238, respectively.

Table 5 Decision-making strategy overall, by phase, and innovation type

Factor		Agent (A)	Outcome (O)	Process (P)
Overall		117	72	108
By design phase	Research	25	17	21
	Analyze	26	16	21
	Ideate	28	5	30
	Build	17	24	22
	Communicate	21	10	14
By innovation typology	Product	40	28	31
	Product-Service	43	25	28
	Spatio-Social	34	19	49

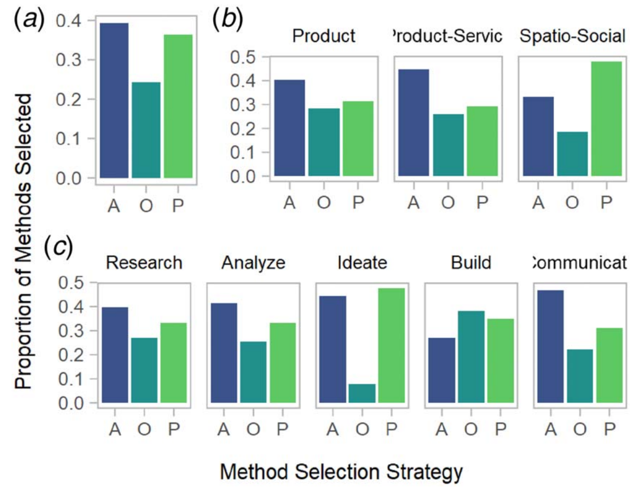

Fig. 1 (*a*) Team selection behavior overall, (*b*) by project type, and (*c*) phase

Using Eq. (1), the method selection difference parameter, we compared the significance of the differences between factor levels of decision-making strategy and project type. We exclude Phase 3: Ideate from analysis because outcome-focused data included outliers—the number of outcomes-driven methods selected was 10—leading to very high proportions for several methods which in turn distorted the data creating false significance in data.

An unpaired Welch's *t*-test, chosen because the number of observed methods selections when organized by innovation type and decision-making strategy are different, revealed a significant difference ($t(186) = 2.57$, $p < 0.05$) in $S_{Mod,i,C}$ between innovation type ($\text{mean} = 0.035$, $\text{sd} = 0.030$) and decision-making strategy ($\text{mean} = 0.048$, $\text{sd} = 0.043$). However, the effect size determined via Cohen's d was determined to be negligible ($d = 0.05$). A Shapiro–Wilk test indicated that $S_{Mod,i,C}$ data organized by six factors (agent, outcome, and process strategies and the three innovation types) were significantly different from a normal distribution ($p < 0.0005$); accordingly, a Kruskal–Wallis test was used to determine that a significant difference existed among the six factors ($\chi^2 = 17.63$, $p < 0.005$, $df = 5$). To examine which factors drove the significant difference, a pairwise Wilcoxon rank sum test was used with Holm adjustment. This test indicated that the only significant ($p < 0.05$) pairwise difference was between outcome- and agent-driven strategies. We note that while agent-driven strategy differed from the three innovation types at a significance level of $p < 0.10$ and the outcome-driven strategy differed from Product-Service innovation at a significance level of $p < 0.10$, neither significance level was sufficient to draw conclusions.

We thus observe that there is a difference in method selection difference parameters between decision-making strategy and innovation type, but the effect size is small. We are unable to conclude which of our three studied innovation types or decision-making strategies significantly drives an observed difference between method selection difference parameters.

6 Discussion

In this section, we consider the implications of findings reported in Sec. 5. We address each research question in light of overall findings.

Table 6 **Significant ($p < 0.05$, Holm-adjusted) differences in decision-making strategies by phase and innovation type with effect sizes**

Selection strategy 1	Selection strategy 2	Difference	Effect size	Cohen's *h*
Spatio-Social—Outcome	Product—Agent	0.22	Small	0.49
	Product-Service—Agent	0.26	Medium	0.57
	Spatio-Social—Process	0.29	Medium	0.64
Ideate—Outcome	Research—Agent	0.32	Medium	0.79
	Analyze—Agent	0.33	High	0.82
	Ideate—Agent	0.37	High	0.89
	Communicate—Agent	0.25	Medium	0.66
	Ideate—Process	0.40	High	0.95
	Build—Outcome	0.30	Medium	0.76

6.1 R1: Absence of Outcome-Focused Selection Strategies. Considering Fig. 1(*a*) and Table 4, it is evident that method selection observed among teams is primarily driven by agent- (39.4% of total) and process-driven (36.4%) factors rather than outcome (24.2%). While the effect size is small, pairwise proportion tests indicate that these differences are real. Much of method selection in novice design teams appears to be governed by individual or team considerations (agent) or contextual factors (process). This suggests that design teams' decision-making strategy is less anchored in design project outcome—a surprising result, especially in HCD projects, where the emphasis is often on user-oriented outcomes [67,68]. This result further highlights the well-established importance of team and contextual factors in team decision-making, such as psychological safety and constraints [69,70].

Exploring decision-making dynamics further, we observed that there are several opportunities to support designers, especially during the Ideate phase (Fig. 1(*c*)) where less than 10% of methods selected were outcome-driven, the pairwise proportion test was significant, and effect size was medium to large. First, for innovation and design teams, this suggests that encouraging greater focus on outcomes of work in the ideation phase could ensure goals of the overall project are considered alongside team

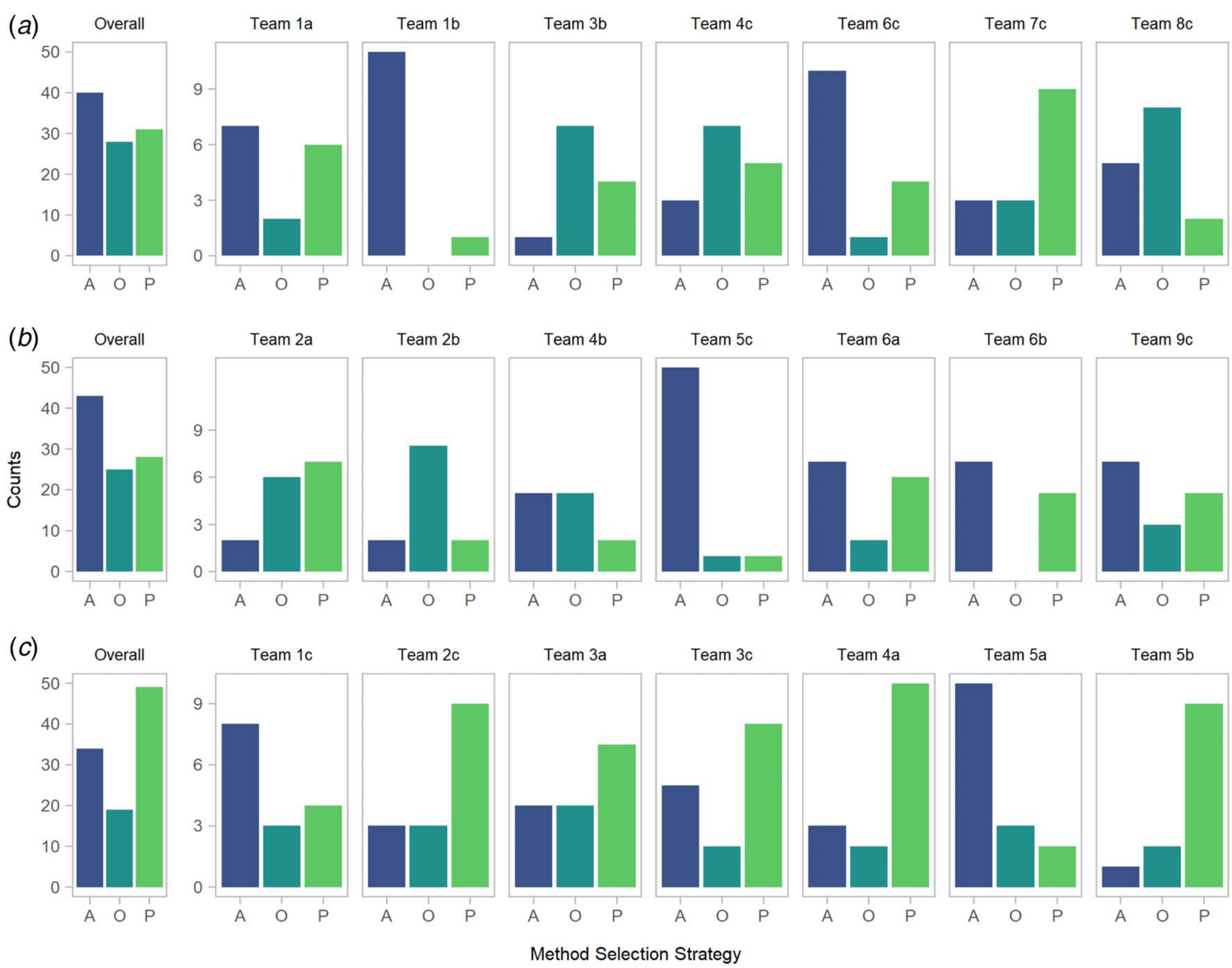

Fig. 2 Team-level decision-making strategy by innovation type: (*a*) product, (*b*) product-service, and (c) spatio-social. Overall decision-making strategy for a given innovation type is shown in the first column. Differing total number of counts by team reflect certain teams' participation in class years when the "communicate" phase was not studied.

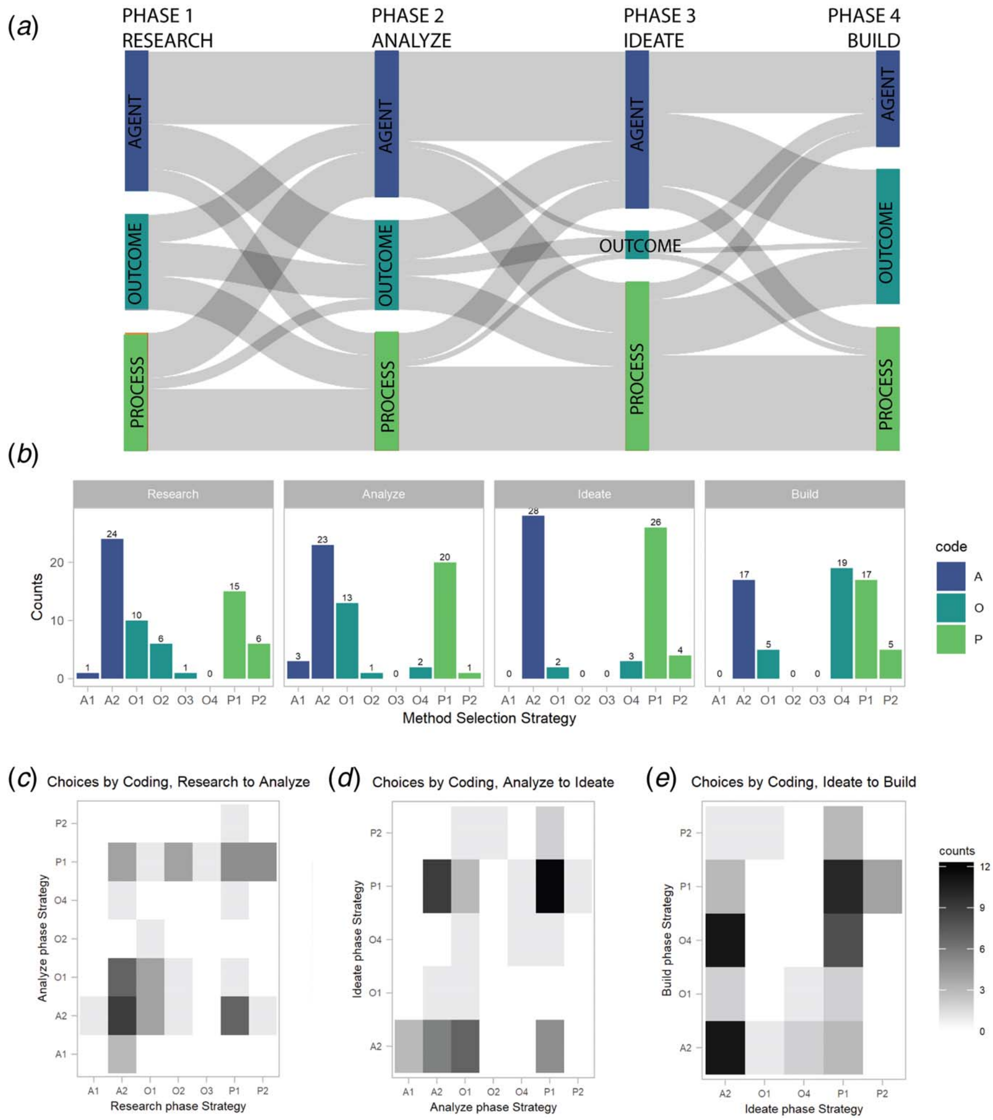

Fig. 3 (*a*) Method selections by particular strategy and relationship to in the subsequent phase's method selection strategy rendered as a Sankey diagram to highlight the flow between the three decision-making strategy categories. (*b*) The strategies employed by the entire cohort at a subcode level are shown and (*c*–*e*) more detail between phases is shown. For example, in (*c*) teams' decision-making strategies in the research phase (*x*) are mapped against teams' strategies in the next phase, analyze (*y*), with darker squares indicating more frequent pairs of decision-making strategies between phases. Due to incomplete data, the communicate phase is not shown.

Table 7 Team rationales with differing innovation types for choosing the same method, the 1:1 interview

Team	Innovation type	Rationale for selecting the method "1:1 interview"	AOP subcode
Team 1a	Product	"Our team agreed to use the 1:1 Interview method to gather insight from our target market in a personal and direct fashion. We also considered using community appraisal, but decided to use 1:1 interview instead since we believe 1:1 interview allows us to narrow down our target group and understand each individual on a deeper and personal level"	O1 (Outcome—user characteristics)
Team 2a	Product-Service	"Since we all come from different backgrounds, early on we adopted an approach that encouraged team members to present ideas backed up by their reasoning"	A2 (Agent—team characteristics)
Team 3c	Spatio-Social	"1:1 Interview is [the] most practical method for us to gather first-hand information with a limited number of team members … we think it is very easy to carry on, and we can get abundant first-hand information about public transportation this way"	P2 (Process—constraints)

Table 8 Team method selections across the four design process phases

	Phase 1: Research	Phase 2: Analyze	Phase 3: Ideate	Phase 4: Build
Method	Person-Objects-Situations-Time-Activities (POSTA)	Customer Journey Mapping	3-12-3 Brainstorming	Tangible Prototype
Justification	"… in terms of the further discussion with the team, it makes possible to share the insights/findings and then compare and compile data most relevantly and conveniently"	"Mapping the customer journey helps us visualizing and focusing on the pains and needs of the customers in sequence of time. With the map, we can figure out some opportunities and design blanks and thus refine the user experience with the detailed information of pains during their customer journey"	"… after one member shared that 3-12-3 brainstorming allows for greater team focus and collaboration, we came to the consensus that working as a team on common ideas using this method would be more helpful than having independent time to work with brainwriting"	"… we thought it would be better to make a tangible menu with our design/drawn stickers to accomplish the building. We choose this build method because we can interact with the physical product much more effectively than a sketch or model on a two-dimensional surface"
Code	A2 (Agent—team characteristics)	O1 (Outcome—user characteristics)	A2 (Agent—team characteristics)	O4 (Outcome—product characteristics)

Fig. 4 Method selection frequency

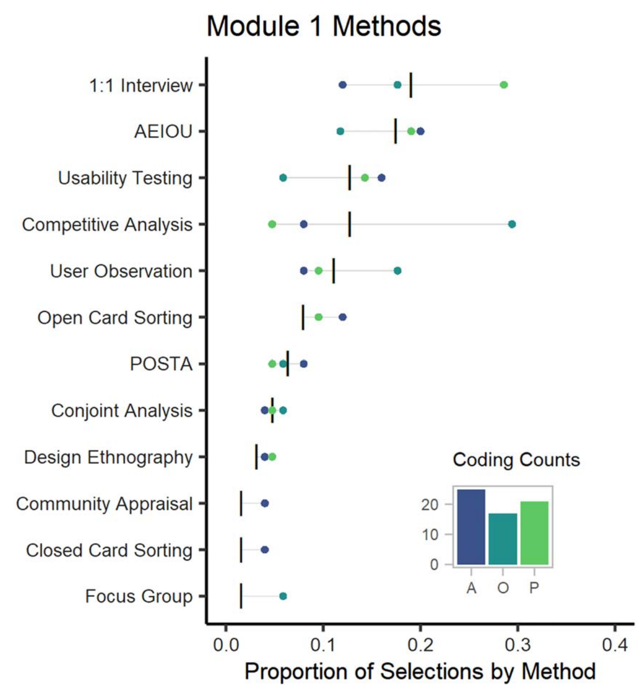

Fig. 5 Method selection by decision-making strategy

and context factors during method selection. Studies often emphasize the importance of time constraints in the design process [71] and ideation quantity [72,73]. These tendencies could have an influence on the decision-making strategy of design teams, by shifting their attention away from the end-user or desired outcome and towards considerations of what is most effective for the team given constraints and requirements. This finding adds effects on team decision-making strategy to the dialog around constraints in design, and in ideation in particular [74,75].

6.2 R2: Method Selection Strategies Among Innovation Types. Spatio-Social projects exhibit a different distribution of method selection compared to other project types, with the highest incidence of process-focused decision-making strategies and the lowest incidence of outcome-focused strategies (Fig. 1(*b*)). This trend is further evident among teams working on Spatio-Social projects (Fig. 2). We reiterate that the differences in observed counts were found not to be significant in a pairwise proportion test, but this is in large part due to the small number of counts (15) per team; our discussion is grounded in a descriptive analysis.

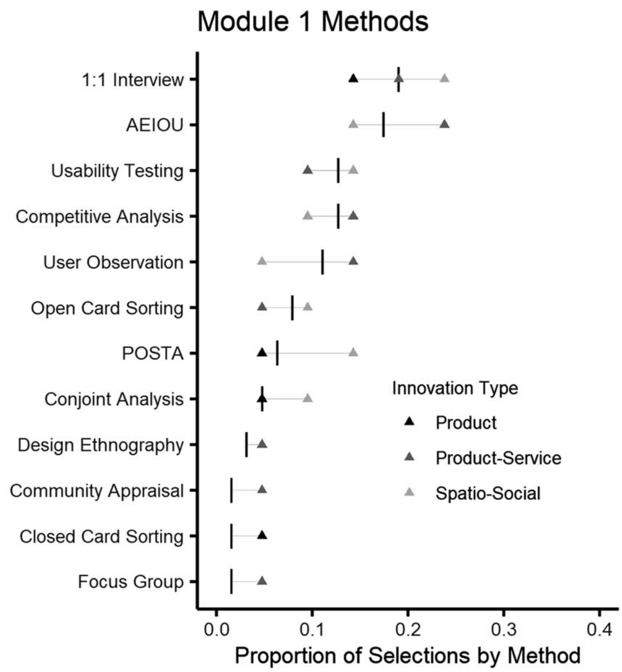

Fig. 6 Method selection by innovation type

These trends suggest that Spatio-Social teams have trouble focusing their decision-making strategy around outcomes when selecting methods. One explanation for this is that Spatio-Social projects are inherently complex in their scope, outcomes, and constituent factors [2,66,76] and could complicate teams' abilities to consider outcomes while engaging in the design process. Revisiting the agent-outcome-process framework, Spatio-Social projects may pose particular challenges in articulating discrete users, markets, and technologies and may not immediately invite discussion about specific products or interventions.

Spatio-Social teams' engagement with process-focused methods-selection is especially notable during the Analyze phase, when teams engage with sensemaking. While Product and Product-Service teams were mostly grounded in agent-focused method selection (47% of all methods selected for both project types), Spatio-Social teams demonstrated process-driven method selection (57%). This in turn shapes the methods that teams ultimately selected. In the Analyze phase, Empathy Maps represented the most popular method for agent- and outcome-driven method selection. However, in process-driven method selection, Empathy Maps ranked seventh. In contrast, the most popular methods among process-driven method selections were the 2×2 Matrix, a tool widely acknowledged for helping make complex problems more accessible [77]. The 2×2 Matrix ranked third among agent- and outcome-driven teams. This suggests that innovation type influences teams' decision-making strategies, and different decision-making strategies lead teams to select different design methods. Spatio-Social innovation teams exhibit very different decision-making strategy patterns than the other two innovation types, explaining some of the difference observed in method selection by innovation type.

Another possible influence is the composition of design teams, which in our data is drawn from novice designers. Expert designers are known to take greater time in engaging with tasks [78] and have been shown to tolerate a higher degree of complexity and uncertainty [79]. Both of these characteristics are particularly relevant to articulating an outcome-focused decision-making strategy in Spatio-Social innovation projects, which present design teams with high levels of complexity. Novice designers' lower readiness in these areas may result in their lack of ability to engage with outcome-focused strategies in complex projects. However, we also highlight that despite the likelihood of experts' higher readiness to engage with challenging aspects of Spatio-Social innovation, even expert designers face challenges in finding a shared language to discuss methods amid uncertainty in the design process [10,80]. This suggests that despite outcome-focused decision-making strategy, unifying strategies with methods would still be of great value to experts.

We note that the above reasons represent our speculations to explain the observed data. Because they are construed from the coding of individual responses, these speculations may not be explicitly reflected in team justifications themselves. For example, while we did not see students explicitly note that they had difficulty articulating discrete aspects of complex problems, we did note responses like that of one team, working on a Spatio-Social project, which point to such challenges (coded P1—Process—Gains):

> While everyone had a very general idea of what was generally associated with campus transit and safety, atomization allows us to perhaps discover details we were not aware of that may provide a solution or a new facet of safety.

Thus, this and other sections' discussions seek to understand trends in terms of decision-making strategy, coded from team decision justifications, rather than the explicit justifications themselves.

6.3 R3: Shifts From User- to Product-Focused Outcome Focus.

While many teams do not change their decision-making strategy between phases (e.g., staying with decision-making strategy A2, team-focused), we focus on those who do (Figs. 3(*b*)–3(*d*)). In particular, the movement towards O1 codes—user-focused outcomes—in the Analyze phase followed by a movement towards O4 codes—product-focused outcomes—in the Build phase highlight a common understanding of how design team focus shifts during the design process. In early stages of the design process, design teams are focused on user needs, while later, they focus on developing a specific product [81]. While it is well-understood that key *activities* in early- to late-stage design follow a user- to product-focus trajectory, it is surprising to see that this mirrored in the decision-making strategy of teams. For example, in the Build phase, this suggests that teams are considering their product, rather than their user, in deciding what methods best express prototypes of their projects. Lauff et al. describe prototypes as tools to help design teams communicate, learn, and decide [82]; if methods to do so are selected with a focus on product rather than other outcomes, teams may be missing opportunities to leverage prototyping methods to communicate and learn holistically about their product. These findings further reinforce the need for support during the prototyping phase that helps a team craft their thinking behind method selection, such as the Prototyping Canvas and the Prototype for X framework [83,84].

Similar analysis can be applied to other phases to reveal opportunities to support teams. In the Analyze phase, teams can be encouraged to consider other aspects of outcomes besides users as they pursue sensemaking activities. Implications of shifts during the ideation phase were addressed earlier. Such support would help ensure that teams engage with the holistic aspects of HCD, considering a variety of factors beyond a singular product or user focus.

An examination of method selection frequency by phase (Fig. 4) reveals several notable findings. First, we are struck that teams rarely select methods because of an outcome-focus on market (O2) or technology (O3). Four methods were selected with O2 or O3 codes: Competitive Analysis, Person-Objects-Situations-Time-Activities (POSTA), Conjoint Analysis, and the 2×2 Matrix. Of these, Competitive Analysis was the only method code O3 associated with. Course material involves examples of products, services, and experiences currently on the market (e.g., Jerry the Bear by Sproutel [85–87]) and discusses underlying technologies (e.g., bluetooth for IoT systems [88]). That students rarely incorporate such thinking into method selection suggests that they need support to map the design process onto technology and market domains [89]. We also note that of these methods, Competitive Analysis, 2×2 Matrix, and Conjoint Analysis are methods that have been adapted from the fields of business strategy and product development [90–92], suggesting that students could associate these methods with these fields.

A second finding from Fig. 4 is that students select different prototyping methods in the Build phase with different strategies. Most notably, Tangible Prototyping and Wireframing were most frequently selected with an outcome-focus on product (O4). Meanwhile, Experience Prototyping was most frequently selected with an outcome-focus on user (O1). Both methods, however, are powerful means of representing a product's function, form and role, to use Houde and Hill's framing of the uses of prototypes [93]. This distinction suggests there are student preconceptions about the value prototyping methods might deliver their team. To challenge these preconceptions, design team leaders could challenge teams to consider all aspects of outcome when selecting design methods.

6.4 R4: Differences in Method Selection Patterns Between Innovation Type and Decision-Making Strategy. Our findings using the method selection difference parameter suggest that decision-making strategy could explain more of the difference in teams' method selections from the cohort average than innovation type (Figs. 5 and 6). We caution that despite the significance of difference in the method selection difference parameter, the effect size is negligible; we are not able to claim a definitive statistical effect. Nonetheless, this finding extends on Fuge et al.'s results that designers' method selections are correlated with project type [21,22,25]. While Fuge et al.'s work examined project topic, we find that innovation type appears to influence decision-making strategy, shaping methods selected. Innovation type alone, however, makes less of a difference than decision strategy.

This added nuance to the relationship between design project and method selection extends the broad themes identified by Fuge et al. while enabling a different path to automated method selection. A support tool, in addition to processing project content and adjacent method selected as previously suggested, could also incorporate measures of design phase and current decision-making approach by the team. This offers a more comprehensive approach to automated design support that could serve to ensure that design teams engage with a diversity of methods in the course of their projects. Furthermore, by associating design phase, innovation type, and decision-making strategy, automated support tools could be generalized to address a variety of design problems, rather than remaining topic-specific or context-specific. Strategy is a concept transferable to various design contexts as is innovation type. This is especially urgent as designers are increasingly tasked with solving complex problems that may simultaneously invoke disparate problem areas (e.g., providing electricity to customers, affecting energy, climate change, and building regulations [94]).

These findings highlight the potential of a deeper understanding of decision-making strategy in design teams. By understanding the reasoning behind designers' behavior, future design tools can be more effective at adaptively supporting design activities in a variety of contexts. We believe a closer investigation into decision-making strategy across a variety of design activities, not just method selection can help make adaptive and automated design support more nuanced and more effective.

7 Limitations

This research has several important limitations. First, course data were collected over a three-year period, featuring two separate instructors. Student cohorts from year one and year three, for example, might have been exposed to slightly different class content, in turn potentially altering their method selection strategy. In the design and roll-out of each course, however, materials were shared between instructors, and the sequencing of data collection for each class was constant.

Second, a key assumption in this work is that methods were selected by teams with thoughtful review and not randomly or unilaterally selected. As we described in Sec. 4, we did evaluate and score team method justifications, but we acknowledge that some teams may have behaved more randomly or perhaps did not thoroughly review all of the methods options before making a choice.

Third, we code team justifications of method selection for the most heavily represented decision-making strategy. In cases where elements of more than one code were evident, the most heavily represented code was assigned. We expect that future studies can examine the multiple decision-making strategy dynamics at play throughout the course of the class.

Fourth, and most foundationally for this work, we use affinity diagramming to surface patterns between contextual factors in literature, which define our framework. As described in Sec. 3, affinity diagramming is inherently subjective and could lead to bias or oversight in the construction of the framework. Other alternatives to affinity diagramming, such as machine clustering via deep learning, have shown promise for applications in organizing design artifacts [95,96] but remain ill-suited for extracting insights from complex design knowledge. We are eager to explore this direction in future work.

8 Conclusions

This work presents an analysis of team decision-making strategy in selecting methods in HCD projects. We present a framework for describing team decision-making strategy and apply it to three years' worth of data from a project-based engineering design course. We examine the influence of project type, as described by the scope of the innovation pursued, and design phase, as outlined by *theDesignExchange*. We find that both design phase and project type influence the decision-making strategies adopted by teams, which in turn shapes the design methods that teams select.

Four results were salient. We observed that teams practice outcomes-focused method selection less than agent- and process-focused methods, a difference especially notable during the Ideate phase. Second, we observed teams engaging with Spatio-Social innovation projects exhibited different decision-making strategy than teams exploring other innovation types. Third, we observed a shift from user-focused outcomes to product-focused outcomes as teams navigated the design process. Finally, we observed that decision-making strategy could possibly explain heterogeneity in teams' method selections more than project types.

All four results have important implications for design team leaders and applications in the development of automated design support tools. We introduce decision-making strategy as a key factor in method selection, and design activities more generally. By understanding the rationale for design team decision-making and its relationship to project phase and project type, automated support tools could more effectively guide and inspire designers as they envision future products, services, systems, and experiences. We hope to extend this work to professional and expert designers in future work.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data sets generated and supporting the findings of this article are obtained from the corresponding author upon reasonable request. Data provided by a third party are listed in Acknowledgement.

Nomenclature

C = factor level, from 1 through 3, representing agent, process, and outcome or the three innovation types

M = the number of methods available to be chosen in a certain phase

N = the number of times the ith method in a phase was selected under a certain factor

$S_{i,Mod,C}$ = the difference between (1) the proportion of methods selected and represented by the ith method, in module number Mod, under factor level C and (2) the overall proportion of methods selected in module number Mod represented by the ith method. We describe this as *the method selection difference parameter*.

Mod = the design phase, with values from 1 through 5, corresponding to the Research through Communicate phases

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