3. METHODOLOGY

Collaborative design involves synthesizing viewpoints, reconciling differences and consolidating commitment to a particular course of action. In the preceding chapter, I outlined the need to understand in greater detail how the interactional work of design collaboration is accomplished with the aid of persistent, shared external representations. This will require a detailed account of the way communicative acts and representational activity are interwoven in processes more generally described in terms of "conscription" (Henderson 1999), "knowledge transformation" (Carlile 2002), and collective "story-making" (Bucciarelli 1994).

This chapter addresses how best to register, hold and analyze the types of complex interaction and the activity that will be the target of my study. It explores issues related to robust case study design, situated work observation and detailed analysis of design interaction. Central to this will be a review of a variety of observational category and coding schemes developed specifically for design activity. Because video data are most useful for fine-grained study of situated work, I will also address methodological aspects of video interaction analysis. It is also necessary to impose a certain structure on the inquiry to ensure that meaningful and robust conclusions can be drawn from a single case. These topics will be discussed prior to the review of observational coding schemes.

Together, these establish the basis for appropriate data collection and analysis to address the roles played by persistent, shared representations in real-time design. In the next chapter, these considerations will be reflected in the initial research design, taking into account salient aspects of the JPL setting. The unfolding of the field research activity will then be described, including responses to evolving insights and unforeseen circumstances that were encountered.

Case Study Methods

The standing design and proposal development teams at Jet Propulsion Laboratory represent a leading-edge concurrent design practice that achieves a high level of performance (cf. Oxnevad 2000, Mark 2002). Featuring intense, co-located sessions with project leaders, scientists and specialists in different domains of aerospace design, the practice emphasizes real-time design decision making. It is also notable for the extent to which it incorporates advanced analysis and modelling tools and the prominent use of shared visual displays. These aspects make the concurrent design practice at JPL well-suited as a site in which to study the use of shared representation in design collaboration. To take advantage of this opportunity, I will discuss relevant considerations from case study method and video interaction analysis below.

Yin (1994) and Stake (1994) discuss concepts, methods and strategies for case-based research intended to enhance study quality and promote the development of generalizable findings. The purpose of the discussion here is not to articulate all aspects of the current study's design; rather it is to introduce a number of terms and concepts that will be referred to in subsequent chapters, as well as in evaluating the overall results and conclusions.

Case Study Designs and Purposes

Yin (1994) describes the case study as a distinct research strategy (alongside experimental, survey, archival and historical research approaches) that is particularly appropriate to address "how" and "why" research questions and contemporaneous, real-world practices. The appropriate case study design depends upon the type of opportunity presented by each case, the phenomena involved and the intended purpose of the overall study. An important early decision is whether a particular study will involve single or multiple cases. When is a single-case study appropriate and what can be learned from it? Yin (1994) allows that findings in multiple case designs are more likely to be generalized and are often considered more robust. However, he emphasizes that single-case studies are appropriate for rare or extreme cases, since these present unique opportunities for insight when few—if any—comparable settings exist. I argue that the JPL setting *is* such an exemplary and potentially informative case.[61]

Yin (1994) describes three purposes for case studies: *descriptive*, *exploratory* and *explanatory*; only the latter are intended to produce causal explanations. Exploratory studies seek to accomplish more analysis than purely descriptive ones, but do so in situations where the depth of understanding does not yet exist to warrant focusing on specific causal propositions or hypotheses. On balance, an exploratory study gains more by remaining open to unexpected phenomena than would be possible with the narrow focus required for hypothesis testing. I undertake this study with a clear orientation toward the importance of shared external representations, based on insights from a body of situated and laboratory studies of design (and other workplace) interaction. This is consistent with the level of rationale and the degree of directedness Yin indicates are appropriate for exploratory case studies—provided they clearly articulate their purpose and the criteria by which their success should be judged.

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[61] Additional background information on the JPL practice is provided in Chapter 4.

In the current study, I wish to understand how participants' interaction with each other, and with various shared representations, contributes to the success of the real-time concurrent design team. Essentially, this is an inquiry into the nature of the work performed by representations in this context. Any analysis constitutes a manner of seeing. This study's purpose is not to explore advanced practices or the performance of this particular team in aerospace design per se. Rather, my goal is to consolidate a manner of seeing design interaction that puts a greater emphasis on the active and constructive roles of shared representations in the collective work of designing—that is, envisioning preferred futures and charting courses of action to bring them about. The research I report below will be a single-case, exploratory study of an unusual, and exemplary case of collaborative, real-time design. I undertake it to provide insight into the communicative and representational activity that is essential to success in such highly-interactive contexts.

Regardless of a study's particular purpose, Yin emphasizes that generalization of case-study findings should be considered on an analytic rather than statistical basis. Rather than comparing studies or making specific predictions on the basis of quantitative results, emphasis should be placed on the utility, applicability and transportability of the analytic approach.[62] Accordingly, the following are criteria for case study quality are suggested.

Criteria for Case Study Quality

Yin (1994) describes four aspects by which the quality of a case study design can be judged: construct validity, internal validity, external validity, and reliability. I will briefly introduce and discuss each below as they will impact the current study's design; I will revisit them as the results are interpreted and discussed.

- *Construct validity* deals with the relationship of the analytic constructs to the case and its objectives. That is, do the constructs apply appropriately and do they adequately encompass the phenomena under study? Can they be applied in a way which is not overly subjective in collecting and interpreting the data?
- *Internal validity* relates primarily to experimental or case research that seeks to support claims of causality. It deals principally with issues of sampling, variable control, and the exclusion of possible external causes and spurious effects. According to Yin, internal validity per se is not an applicable criterion for exploratory case studies; however the root issue remains: whether or not inferences about relationships between the phenomena observed are made in a robust manner.

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[62] Stake (1994) argues for the intrinsic value of richly descriptive cases, and is less concerned than Yin with explicit generalization (cf. "learning from the particular" and "naturalistic generalization," pp. 238-240). He does distinguish between cases undertaken for instrumental vs. intrinsic matters of interest.

- *External validity* deals with the generalization of findings. How applicable are findings likely to be to other cases? Do they contribute to a theory that will prove useful, convey insight or have implications in other situations?
- *Reliability* deals with the minimization of errors and bias. If another researcher were to follow the methods described, would he or she arrive at the same findings and conclusions?[63] Since it is usually not practical—or even possible—for a different researcher to repeat *the same* case, reliability in case studies often rests upon thoroughness, clarity of method and quality of documentation.[64]

Robust Analyses in Case Studies

A number of factors contribute to the overall robustness of analyses in case studies; several of these are particularly afforded by the JPL setting. Factors discussed below include appropriately *bounding* the case, discerning relevant *units of analysis*, identifying clear *predictor and criterion variables*, and employing some form of *triangulation* when making interpretations.

Both Yin (1994) and Stake (1994) discuss the importance of appropriately bounding a case study. Boundaries drawn too narrowly exclude important or decisive factors, compromising the validity of the study's findings. Overly-broad boundaries make cases unmanageably complex, inclusive of so many phenomena that theoretical refinement in any particular area becomes difficult. Observations in the JPL setting will be more limited than would be the case in an ethnography (e.g. Hammersley & Atkinson 1995, Schwartzman 1993).

However the JPL context affords bounding in ways that other concurrent design settings do not. Design activity is concentrated in co-located sessions, typically 3-4 hours in length. Emphasis is placed on exploring ramifications and making design decisions *in* these sessions—with customer feedback and subject to cross-domain scrutiny. This means that design reasoning is both relatively explicit *and* localized in time and space, enabling a more comprehensive record of relevant interaction to be made.

Yin (1994) discusses the importance of deriving appropriate units of analysis from the central propositions and concerns of the case study. Units of analysis are entities discerned

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[63] Reliability is a precondition, but should not be confused with replication. Yin distinguishes between literal replication, which denotes the same findings arising in nominally similar cases, and theoretical replication wherein findings from two or more diverse cases lend support to the same theory—and not to rival theories.

[64] In the application of coding schemes, the degree to which different researchers code the same data identically is referred to as inter-coder (or inter-rater) reliability. Opposing views of the importance of inter-coder reliability are presented by Nyerges et al. 1998 and Morse 1997.

within the data and used as the basis for analytic comparisons.[65] Yin distinguishes between *holistic* case designs, in which the entire case comprises a single unit of analysis, and *embedded* designs in which multiple units of analysis are identified.

As I will describe in the chapters that follow, resolution of tensions concerning units of analysis will be one of the principal learning outcomes—and an area in which challenges remain at the conclusion of this research. In the JPL setting, clearly-defined domains of expertise and the regularity with which the teams work on design projects offer potentially useful delineation for units of analysis. However, the interdependent and contingent nature of design reasoning between domains presents complications, as do the novel and innovatory aspects of every project undertaken at JPL.

To make analytic comparisons between units of analysis, one of the principal modes of case-study analysis Yin (1994) describes is pattern matching. In explanatory (or causal) studies this requires a clear conception of dependent and independent variables.[66] More generally, pattern matching requires articulation of the outcomes of interest (desirable or undesirable), and the various potentially-contributory factors, as part of a strategy for making the most informative comparisons and contrasts.

> The role of the general [pattern matching] analytic strategy would be to determine the best ways of contrasting any differences as sharply as possible and to develop theoretically significant explanations for the different outcomes. (Yin 1994, pp. 109-110)

In complex human systems, the assumption that "variables" can be isolated and manipulated independently of one another, and correspondingly simplistic notions of causality, are often misleading. Accordingly, I intend to employ the terms "*criterion variable*" and "*predictor variable*" (Wuensch 2004) to refer to outcomes and contributory factors in this situated, non-experimental study.

A final factor in the robustness of any qualitative research is *triangulation*. Yin (1994) discusses this primarily as a matter of obtaining evidence from multiple sources. Stake (1994) elaborates triangulation more generally as an approach to clarifying meaning, verifying observations and interpretations, and illuminating the diverse ways in which "the same" phenomena may be perceived. In assessing predictor and criterion variables,

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[65] For example, the units of analysis employed in Barron's (2003) study of student problem-solving performance (discussed in Chapter 2) were individuals and triads.

[66] In experimental research, independent variables are those that are manipulated, and dependent variables are those whose behaviour is observed. Proper experimental design excludes extraneous and confounding factors so that an inference of causality can be made on the basis of correlation between the behaviours of independent and dependent variables.

triangulation is desirable both with respect to what can be said to have occurred in interaction, as well as in the assessment of outcomes.

The methods of interaction analysis, particularly from video data, and the observational coding schemes discussed below provide additional insights into the identification of appropriate units of analysis and predictor/criterion variables. These are highlighted again in the design and conduct of the research activity, presented in the following chapter.

Interaction Analysis

The objective of this research requires observing authentic, organizationally situated work interaction, unfolding in real time amidst shared representational artefacts and technologies. This level of analysis is comparable to the situated action studies discussed in the preceding chapter, and I anticipate the use of video data will therefore be essential. For this reason I include a brief overview of general considerations in video interaction analysis prior to reviewing actual coding schemes for design activity.

The availability of video recordings greatly facilitates fine-grained study of interaction between people and material artefacts (cf. Heath & Luff 2000). In their discussion of techniques and methods for video interaction analysis, Jordan & Henderson (1995) call attention to several potential foci for this type of analysis:

- *The structure of events*: includes beginnings and endings (both official and unofficial), segmentation and transitions; shifts in topic and/or in the modalities of engagement w/ artefacts; entry into patterns or "projectable" interaction sequences[67]
- *The temporal organization of activity:* distinction between macro vs. micro levels of analysis (detailed below); external demands that drive patterns in interaction; rhythm and periodicity (e.g. intense vs. slack times), etc.
- *Turn-taking*: in speech, movement, engagement w/ artefacts; whether these are talk-driven or instrumentally-driven; apparent "interruptability," proactive vs. passive engagement, etc.
- *Participation structures*: shared attentional focus, task orientation, visual and auditory availability; principled or patterned inclusion or exclusion of participants
- *Trouble and repair*: breaches between participants with regard to intentions or understandings; breakdowns involving environmental resources and technologies

[67] "Projectability" is a term drawn by Jordan & Henderson from Conversation Analysis (cf. Schegloff) denoting the creation of reliable expectations on the part of participants with regard to the way subsequent conversational events are likely to unfold, including the range of responses deemed appropriate in a given situation.

- *The spatial organization of activity*: configuration of individuals in space, their orientation, access to resources etc.; 'ownership' of territory where interaction takes place; arrangement of furniture, its fixity or responsiveness
- *Artefacts and documents*: creation and inscription, trajectories of use, involvement in activity segmentation; apparent 'ownership', whether they are private or shared

These foci convey the authors' accumulated wisdom regarding the phenomena that tend to be most informative for interaction analyses in general. Beyond the obvious attention to artefacts and documents this study will require, I would like to expand upon three of the topics that will prove particularly useful in structuring the inquiry at hand.

Macro vs. Micro Levels of Analysis

In contrast to long-term temporal patterns and macro-scale orderliness embodied in projects and organization structures, Jordan & Henderson describe the concern of interaction analysis with the temporally fine-grained, moment-by-moment unfolding of interactional events:

> Interaction Analysis provides a focus on the shape of an event, its high and low points, the relaxed and frenzied segments, and the temporal ordering of talk and nonverbal activity. Above all it gives access to the ways in which participants experience and make visible the temporal orderliness and projectability of the events they construct. (Jordan & Henderson 1995, p. 61)

This raises the issue of *levels* of analysis. Design can conceivably be studied at any of a number of levels, including that of the individual (considered intra or inter-psychologically), small group, community, organization, industry, profession, or culture.[68] In any case, in focusing on a relatively micro-level of video analysis it is important to retain an awareness of how any particular episode is situated within a larger web of activities (Bødker 1996), and to highlight how these connections may be manifest in interaction.

Micro-level analysis involves the actual sequence and content of individuals' conversational contributions in continuous episodes of coherent interaction, usually measured in minutes. Analytic judgements are based participants' awareness of events and behaviour bounded by this context, not on events that occur later, or of which participants could not have been aware at the time. Macro-analysis, on the other hand, refers to longer timescales—hours, days or weeks—over the course of which discrete and temporally non-contiguous events and developments may be selected and interpreted to reflect the evolution of projects and

[68] Some modes of analysis, such as that of the community-of-practice (cf. Lave & Wenger 1991) or activity system (cf. Engeström et al. 1999) cut across conventional levels. Others, such as actor-network theory (cf. Latour 2005) argue that these levels are primarily artefacts of prior theorizing whose existence should not be assumed a-priori.

outcomes. My analytic focus will be on the accomplishment of interactional work (consistent with the theoretical resources I identified in the previous chapter); I will also endeavour to highlight where phenomena may bear upon extant theorizing at other levels, recognizing that comprehensive analysis may involve both micro and macro levels.

Segmentation and Units of Analysis

Because interaction analysis at the micro level tends to be labour intensive and time-consuming, it is important to focus attention as carefully as possible on bounded segments that are likely to be the most analytically productive. (This is consistent with Yin's (1994) description of the analytic strategy of pattern matching.) For this purpose, Jordan & Henderson advise attending to various aspects of participants' own segmentation of their activities. These takes the form of announced beginnings and endings, informal transitions and participation structures—regularities in the individuals present for a common task or sharing an attentional focus.

The JPL setting presents particular affordances for segmentation and for observing participation structures. Patterning of the work of mission and spacecraft design, developed in this practice over the years, is reflected in the distinct domains of expertise and certain recurrent tradeoff decisions between design approaches. These present opportunities for segmentation, and a possible basis for units of analysis, the nature of which I will come to better understand after entering the research setting (as I describe in subsequent chapters).

Attention to Trouble and Repair

In the midst of otherwise seamless and fluid task performance, Jordan & Henderson advise that instances of trouble and repair may be particularly revealing:

> Anthropologists have known for a long time to pay particular attention when the normal stream of activity is broken in some way. Careful analysis of the breach can often reveal the unspoken rules by which people organize their lives. As a matter of fact, the analysis of visible breaches of the local rules for social interaction is one of the best methods for coming to an understanding of what the world looks like from somebody else's point of view. Analysis of hitches in interaction may also reveal some of the constraints in the material world that routinely cause trouble. (Jordan & Henderson 1995, p. 69)

Similarly, Bødker (1996) highlights the use of breakdowns to identify the ways in which activities intersect and interfere with one another, or points at which artefacts fail to offer adequate support. While periods of highly productive design interaction will obviously be of interest, this suggests that instances of confusion, frustration and communicative repair should also play a role in analytic pattern matching.

With considerations of case study method and video interaction analysis in mind, I will now review a range of observational coding schemes for design activity. Rather than developing emergent coding categories from scratch (cf. grounded theory, Strauss & Corbin 1990, 1994), I intend to draw upon the categories embodied by these schemes, determining which are most useful based upon my actual data. This appropriately reflects the exploratory (vs. descriptive) orientation of this study, and enhances construct validity by establishing continuity with a substantial body of prior research on design interaction.

Observational Categories and Coding Schemes

Collaborative design involves synthesizing viewpoints, reconciling individual differences and consolidating commitment to a particular course of action intended to bring about a preferred future reality. Essentially, this is a process of collective reasoning. A number of observational coding schemes have been developed, which I proceed to describe in this section, ranging from abstract and formal conceptions to more mundane descriptions of the acts involved. Among the more salient distinctions are those between design reasoning as fundamentally directed vs. iterative, between various aspects of process and content, as well as shifts in communicative modality, the use of external media and the temporal locus of discourse. An additional, fundamental distinction is between coding that is essentially *categorical*, and *structural* coding that emphasizes referential connections over categorical judgments.

Design Reasoning: Formal Logic

Some coding schemes seek to consolidate design reasoning into the logical structure of formal argument, while others focus on categorizing the variety of acts involved. The poles of this continuum correspond generally to the two metaphors from Chapter 2—that is an abstract or formal conception (e.g. design as search) vs. a transactional one (design as conversation).

Focusing first on logic, schemes developed for design rationale capture seek to formalize design reasoning in an argument structure. This is motivated by the need for organizations to recall the reasoning behind product definition and design choices after the groups directly involved have disbanded. Olson et al. (1992, 1994, 1995) present a categorical coding scheme based upon a conception of design reasoning as a process of argumentation involving *issues*, *alternatives* and *criteria* (IAC). Shum et al. (1997) and MacLean et al. (1991) report a similar coding system based on *questions*, *options* and *criteria* (QOC). In both cases, design rationale is embodied in the relationships between the problematic aspects and alternatives identified, and in positive or negative assessment of these against various criteria.

Olson et al. perform a sequence analysis on transitions between their core IAC categories to discern a "grammatical" sequence for "direct design activity" (Olson et al. 1995, p. 229). Frequently, this involves a transition from a management topic that leads to the identification of an issue, followed by a looping discussion of alternatives and criteria (Olson et al. 1995, p. 231). Olson et al. point out that their coding scheme does not track relationships between issues or which participants make specific contributions. Represented in this way, design rationale may appear singular and unitary, not reflecting systematic disagreement or differences of opinion among participants.

Shum et al. (1997) develop a graphical tool to provide real-time support for groups wishing to explicitly understand the argument structure of their design decisions and to capture their design rationale. As Shum et al. point out, collaborative development allows the degree of group "ownership" of any such representation to be assessed. They also note, however, that prototype rationale capture systems appear to slow interaction and to impose an additional cognitive burden on design teams. It appears that, to whatever extent design reasoning involves QOC or IAC argumentation, constructing an explicit representation on this basis (at least with current tools) is not a transparent operation for real-world design teams.

Design Reasoning: Action (or Transaction) Structure

Other schemes emphasize the transactional structure of design reasoning by categorizing the types of acts involved. This is reflected by category names that tend to be transitive verbs rather than nouns. The focus of some schemes is quite fine-grained—describing the constituent elements—while others seek to convey a more overall description of the shape and direction of design processes.

An example of the more fine-grained type of scheme was introduced in the preceding chapter (in the context of co-construction of design representations). Fleming (1998) presents a compact typology of essential linguistic acts in design: *indexing*, *constituting* and *elaborating*. Indexing talk is that which picks out distinct features and foregrounds the compositional nature of the object at hand. Constituting talk fixes aspects of form with respect to the agency of the designers and their intentions. Elaborating talk locates these features more extensively with regard to the design context, enduring principles, pedagogical objectives etc.

For example, in discussing a brochure she is creating with a colleague, a graphic designer might *name* a particular part—identifying an introduction for example. She might proceed to describe (or *constitute*) this in terms of the use of a particular font or other typographic feature, mentioning intentional attributes such as a warmer or more engaging tone. The colleague might concur and *elaborate* this decision in terms of a more general principle, such as the need to draw the eye or invite the reader to enter the text at a particular point. According to Fleming, it is the combined effect of all three types of talk that renders design objects durable and "rhetorically consequential" (Fleming 1998, p. 49). Co-construction comes about through the combined effect of these kinds of talk, and their potential contribution by multiple individuals in social situations of collective designing.

A similarly fine-grained perspective on design reasoning, based on Schön's concept of reflective practice, is presented by Valkenburg & Dorst (1998). This typology consists of four acts: *naming*, *framing*, *moving* and *reflecting*. The first act, *naming*, deals with identification and isolation of features while *framing* establishes (often metaphorically) relationships between these and possible goals and actions. The third act, *moving*, is essentially an intervention—an experiment or proposed alteration within the context created by the frame. Finally, *reflecting* involves assessment of the results of moves with respect to desirable outcomes.[69]

Though these categories are defined on the basis of acts rather than formal logic, the schemes remain somewhat abstract in that they do not explicitly include some of the more mundane activities that comprise design conversations. Brereton et al. (1996) propose a coding scheme that explicitly recognizes additional aspects of conversational interaction and collective reasoning in group design process. This scheme comprises the following categories based on participants' acts:

- calling and engaging focus
- proposing or adding to a partial solution
- supplying supporting rationale, justifying on the basis of abstract principles
- illustrating by way of use-scenarios
- acknowledging
- calling into question
- requesting or expressing need for further information

[69] Mabogunje (1997) investigated the relationship between naming per se and the performance of student design teams during an extended project course. Applying automated content analysis to design documents and specifications, Mabogunje found a positive correlation between teams' final grades and their naming activity, manifest in the steady development over time of a rich, project-specific language for requirements and solutions.

- aligning with or distancing themselves from approaches or aspects of evolving solutions

Analyzing the same data as Brereton et al., Cross & Cross (1996) [70] present a scheme highlighting aspects of teamwork and social process. These include *establishing roles*, *gathering information*, *analyzing problems*, *building concepts cooperatively*, *employing persuasive tactics*, and *avoiding and resolving conflict*. Taken together, these schemes identify the constituent elements and acts through which collective design reasoning proceeds.

Linear Progression vs. Iteration

Whereas the schemes above focus on the constituent acts, other schemes offer more of an overall description of the way in which design reasoning unfolds. These often embody two distinct schemas: one a linear progression or trajectory derived from a sequential model of problem solving, the other emphasizing iteration or a recursive co-evolution.

Austin & Steele (2001) report on the temporal progression of conceptual design conversations in architectural design. They employ a descriptive category scheme for activities ranging from conception of the business need and functional requirements to the detailed development and costing of options. Despite their initial assumption of a relatively linear process (*interpret*, *develop*, *diverge*, *transform*, *converge*), they find notable iterative patterns in their observational data. Significant iteration occurs within sub-activities in each phase, and also in significant backward looping to previous phases. Steele et al. (2000) suggest this pattern reflects the discussion of solutions giving rise to a better understanding of the problem, requiring back-tracking to revisit and revise both.

Recognizing backward loops as evidence of problem redefinition, Austin & Steele point toward a concept more fully developed by Dorst & Cross (2001) and Cross (2002). This is a view of design activity that essentially involves a co-evolution of understanding in problem and solution spaces, with each exerting a mutual constraint upon the other. [71] Bridges between the evolving problem and solution spaces are experienced by designers as emergent insights—often accompanied by enthusiasm and excitement.

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[70] Cross, Christiaans & Dorst (1996) is a comparative volume in which data from the same experimental study (designers working individually and in a group on a laboratory design task, known as the Delft Protocols Workshop) were analyzed by diverse researchers (including Brereton et al., Mazijoglou et al., Cross & Cross cited here).

[71] Dorst & Cross (2001) attribute the co-evolution model to Maher et al. in Gero, J.S. & Sudweeks, F. (Eds.). (1996). *Advances in Formal Design Methods for CAD*. London: Chapman & Hall.

Stempfle & Badke-Schaub (2002) also describe designers' intentional action in goal and solution spaces, proposing basic cognitive operations that correspond to notions of convergence and divergence.[72] The first two cognitive operations, *generation* and *exploration* widen the problem space, while the second pair, *comparison* and *selection* narrow the problem space. On the basis of transition frequencies, Stempfle & Badke-Schaub (2002) found *solution generation* most frequently followed by a repeated loop of *analysis* and *evaluation,* a cycle they assert constitutes "the core of the collective thinking process" (p. 487). Stempfle & Badke-Schaub interpret this behaviour as a reflection of the need for designers to maintain the set of issues and alternatives they consider within a cognitively manageable range.[73]

Also linking abstract conceptions of divergence and convergence to empirically-observable behaviour, Eris (2002) correlated question-asking in student teams, engaged in a laboratory design exercise, with their task performance. Eris reviews alternate categorization schemes for questions, finding the greatest explanatory power in a distinction between deep reasoning questions (DRQs, citing Graesser 1988, 1993, 1994), and what he terms "generative design questions" (GDQs). While DRQs are specific questions asked with an apparent expectation on the part of the speaker of a single (i.e. correct) answer, GDQs are asked without any such apparent expectation (i.e. in an open-ended or speculative manner, for the purpose of soliciting alternatives, etc.). Eris interprets GDQs as essentially reflecting a divergent mode of thought, while DRQs are indicative of convergence. Eris finds a positive correlation between team performance and *combined* GDQ and DRQ asking rate, with no strong correlation for either category considered by itself. Eris interprets this finding to support the idea that productive design activity involves a balance between diverging and converging discourse.

Process vs. Content

A number of schemes employ some distinction between the content of design reasoning and various aspects of process. Here, "content" generally refers to discussion of problems, solutions, criteria etc. seen as the core activity in design reasoning. "Process" can refer to

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[72] With regard to personal preferences in problem solving, the terms "converger" and "diverger" were used by Hudson (1968) to describe the performance of English schoolboys on open-ended tests intended to complement conventional IQ tests. Convergers were those who excelled on standard IQ tests but dramatically under-performed others—whom Hudson labelled divergers—on open-ended alternative tests. Hudson characterized convergers as those particularly attracted to the notion of a single right answer, while such a notion seemed almost repellent to the divergers.

[73] Stempfle & Badke-Schaub (2002) identify two process variants with regard to solution generation and evaluation: one process generates and rapidly evaluates ideas until a satisfactory solution is found, while the other undertakes a greater level of analysis of each idea prior to evaluation. The latter is more likely in groups that explicitly adopt some form of normative process.

designers' reflecting upon their own process, i.e. with regard to the order of tasks or problem-solving tactics. Stempfle & Badke-Schaub (2002) make a such a distinction, reporting that the teams in their study engage in process-related exchanges compared to content-focused ones in a ratio of approximately 2:1. They propose, however, that the same basic thinking operations (i.e. *exploration*, *generation*, *comparison* and *selection)* underlie analogous processes in both the content and process domains. Minneman (1991) also identifies distinct "facets" of design conversation that include process, roles and relations, in addition to discourse addressing the designed artefact itself.

Another dimension of "process" arises when design work is embedded in organizations, consequently giving rise to concerns that are more logistical, programmatic or political in nature.[74] Coding schemes such as that of Olson et al. (1995) have categories for *project management*, *meeting management* and *summarizing*, in addition to the core categories for design reasoning. This facet of real-world design activity is likely to be particularly salient comparing student or laboratory studies to those that are more organizationally situated. In the latter, conversation about the envisioned artefact in the future context is likely to be interspersed with discussion of the very real constraints of the organizational here-and-now—in addition to the designers' meta-discourse to manage their collective process in real-time.

Shifts in Modality, Medium and Temporal Locus

A number of studies use coding categories derived from the communicative modalities and media employed by participants in design conversations. These include, for example, shifts between periods of interaction dominated by speech alone vs. drawing, symbolic writing or engagement with artefacts. In general, studies attending to these shifts have not proposed such strong overall process models as those reviewed above; they do nonetheless suggest that certain activities or sequences of activities are essentially involved in productive designing.

Reid & Reed (2000) employ a coding scheme to distinguish between *figural* and *conceptual* design arguments employed by members of the student teams they observe. Figural arguments involve visual activity—such as sketching, pointing or figural gesturing—while conceptual arguments are primarily non-visual. As dependent measures, Reid & Reed use the rate of turn-taking to convey the tempo of the design interaction and the level of participation of group members.

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[74] These may require a different theoretical basis for abstraction, such as found in sociology or organization theory (cf. Hargadon & Fanelli 2002, Hargadon & Sutton 1997).

> Thus, high turn rates indicate periods of highly interactive design reasoning, characterized by brief contributions and a brisk exchange of arguments, often between several group members. Low turn rates indicate fewer interactive periods consisting of 'megaturns' (Dabbs & Ruback, 1987), in which individual group members hold the floor more or less continuously while others offer brief comments or questions. (Reid & Reed 2000, p. 364)

To understand the temporal structure of these episodes, Reid & Reed performed exploratory spectral analysis, looking for periodicity in figural and conceptual argumentation, turn taking and participation. They found cycles on the order of five to ten minutes, in which a period of figural (e.g. sketching) activity appeared to lay the groundwork and then give way to highly interactive conceptual discussion. [75]

> This analysis suggests that figural reasoning plays a prominent lead role in the majority of design episodes, not only entraining the phasing of group participation and turn-taking cycles, but also entraining cycles of conceptual reasoning. (p. 368)

Whereas Reid & Reed (2000) employ a fairly simple distinction between figural argument and conceptual argument, Tang (1989, 1991) and Tang & Leifer (1991) find that the prominent modalities employed in design conversation include *symbolic writing*, *drawing* and *gesture* as well as speech. Attempting to track ideas from proposal to acceptance, Tang finds each type of workspace activity potentially serving three functions: *storing information*, *expressing ideas*, and *mediating interaction*. In particular, Tang (1991) notes that gesture accompanies over 30% of the workspace activity in some segments. Also interesting is the observation of repeated or iconic gestures employed by participants to index earlier episodes of talk, as a way of reintroducing a previous topic or idea.[76]

Mazijoglou et al. (1996) focus particularly on the interplay between design discourse and the evolution of sketches in a shared drawing space. This study combines a relatively straightforward discourse typology of *problem*, *solution*, *constraint*, *requirement*, *information need* and *process*, with an elaborate coding scheme for drawing activity comprising *non-symbolic* (doodles and squiggles), *alphanumeric* (labels and writing), *other symbolic* (underlining, arrows), *pictorial orthographic* (plans, sections) and *pictorial perspective*. Three analytic representations are used to develop and present findings:

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[75] Studying individual designers, Akin & Lin (1996) attempted to correlate episodes of multiple-modality activity (e.g. drawing, writing, etc.) with demonstrably novel design decisions (NDDs). They found the emergence of a majority of NDDs co-occurred with episodes of heightened triple-mode activity during otherwise relatively quiescent periods. This may be indicative of the lead/lag relationship found by Reid & Reed.

[76] Brereton (1999) also codes transitions between modalities of conceptual argument and engagement with hardware, finding that students in teams learn abstract engineering concepts most effectively when their discourse involves frequent transitions between modalities. This appears to be the case both with regard to rough prototypes created by students and in their dissection of existing products.

transcriptions of discourse (coded by turn) and networks reflecting transitions to and from episodes of drawing activity as well as the structural (i.e. precedence) relationships between various elements of drawings.

Mazijoglou et al. find more solution-focused discourse associated with increased visualization, while information-focused discourse is associated with writing activity. This study illustrates the use of distinct categories for discourse and for drawing acts, and the possibility of relating these analytically. It also highlights how the development of drawings occurs in conjunction with the advancement of design reasoning in discourse, and suggests the possibility of tracking referential structure between the two. Discussion of certain issues or ideas may become localized on the drawing space such that discourse transitions are coordinated with, and facilitated by, shifts in the locus of activity in the drawing space.

Linking discourse to drawing space evolution, Mazijoglou et al. draw attention to a class of utterance called concrete, third-person deictic references.[77] In using discourse deixis to track participants' use and reference to the drawing space, Mazijoglou et al. note, however, that many instances of expressions such as "it" and "its" did not relate to anything in the drawing space, but instead, "seemed to refer to abstract design solutions shared by the designers and held in their minds" (p. 397). Thus, while the locus of drawing activity can index discussion of certain issues or ideas, it can not convey the entirety of reasoning in a design conversation.

The movement of the design group's attention across the drawing space noted by Mazijoglou et al. is elaborated by Taura et al. (2002). This study employs a fairly straightforward, linear problem solving sequence (*awareness of problem*, *suggestion*, *development*, *evaluation* and *conclusion*) in conjunction with the notion of a "gazing point" that encompasses time, aspects of objects and 'non-objects.' Possible gazing points include the state, constraint, or purpose of the design object, background knowledge, documents or apparatus, the presumed use scenario, relevant past experience or future plans, and relevant past design activities. Taura et al. propose that a "gazing point control process" operates in parallel with the designer's problem solving; they illustrate this by mapping specific gazing points onto design proposals at various points in the design process.[78] Their articulation of the attributes and diversity of gazing points is useful to suggest the kinds of things that may

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[77] These are short, pronominal words, such as *he*, *she*, *it*, *this*, *that*, *here* and *there* (also described as indexical expressions) whose meaning can be interpreted only with recourse to the context of use.

[78] Taura et al. compare two individual designers (an experienced designer vs. a student), so their results are not directly relevant to this thesis. However their method is notable in that it integrates after-the-fact review of videotaped sessions with the designers themselves, during which an interview protocol is used to query the designer's reasoning and rationale for observed shifts in their gazing points.

be represented in a design conversation, beyond the drawing activity studied by Mazijoglou et al.[79]

These studies draw attention to a number of phenomena, but also illustrate the potential difficulty of relating patterns in cross-modal activity to meaningful conclusions about the productivity of design reasoning. What is missing is a more direct connection between particular patterns of representational activity, and beneficial process attributes or demonstrably noteworthy outcomes.

Structural vs. Categorical Coding

Analysis such as that employed by Mazijoglou et al. (1996) involves registering connections between designers' conversational contributions and various parts of drawings. While they emphasize categorical attributes in their findings (i.e. mapping types of drawing act onto formal process stages), Mazijoglou et al. mention the possibility of restructuring the analytic representation of design activity in a manner that "links all workspace activities to drawings and other artefacts in the design space" (Mazijoglou et al. 1996, pp. 404-405). This suggestion is a step toward a fundamentally different coding approach, one that emphasizes judgements of structural *connectedness* over category membership.

Developing such an approach, Goldschmidt (1992, 1995) and Goldschmidt & Weil (1998) present a method known as "linkography." Rather than categorizing moves solely on the basis of a formal typology, linkographic coding establishes links between moves on the basis of a perceived referential commonality in the context of the design object.[80] A particular move may be linked to one or several other moves, which may have preceded or followed it. Goldschmidt identifies the density of such linkages as an indicator of the productivity of conceptual design conversation, both on empirical grounds and based on the idea that productive design conversation is inherently generative and integrative.[81]

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[79] Minneman (1991) also distinguished between substantive "facets" in discourse (artefact, process, relations/roles) and temporal "trajectories" (making sense of the past, understanding the current state, proposing future action).

[80] "In practice, a link between two moves is established when the two moves pertain to the same, or closely related, subject matter(s), such as a particular component of the designed entity, its properties and functions, a concept or a design strategy, and so on" (Goldschmidt & Weil 1998, p.90). Goldschmidt and Weil define the criteria for assessing connections in terms of "common sense" (ibid., also cf. Goldschmidt 1995, pp. 195-196).

[81] Goldschmidt relates her conception of productive designing to gestalt psychologist Max Wertheimer's (1945) view of productive thinking as that which gives rise to genuine ideas, understanding and creativity as opposed to rote thinking and routine. Goldschmidt (1992, 1995) uses metrics to relate overall link density to productivity of design conversations, also identifying "critical" moves deemed to have been particularly generative or integrative based on their unusual density of connections.

Linkography is of interest as an orthogonal approach to content coding that transcends the descriptive limitations of specific, categorical schemes with respect to the content of design reasoning. There is an essential, constructive aspect to productive design conversation: its development necessarily entails movement and its outcomes embody some form of novelty. This movement is impossible to render (at a level of topical specificity) with a categorical scheme, precisely because the object of discourse is continually evolving and changing. As Goldschmidt and Weil note, a detailed understanding of design reasoning requires attending both to the categorical composition and the structural connectedness of discourse.

> [design reasoning] moves forward but also makes sure that it is congruous with what has already been achieved, and it validates what has been done thus far with an eye on ways to proceed from that point. ... We propose that this pattern represents a cognitive strategy that ensures the efficiency and effectiveness of reasoning in designing: it ensures continuity while also guaranteeing that progress is made, and it serves the need of sustaining a solid and comprehensive design rationale for the entity that is being designed. The success of this strategy hinges on an equilibrated relationship between structure and contents, such as we found inherent in design reasoning. (Goldschmidt & Weil 1998, p. 100)

The types of referential connection highlighted by linkography appear to be most relevant to idea generation and brainstorming activity. Though undeniably of interest, this is only a fraction of what takes place in real-world, situated designing. In the latter, referential linkages are likely to be far more complex and require more explicit criteria and differentiation than Goldschmidt provides. Laboratory settings, without an independent way of assessing the quality of design process, make it difficult to meaningfully ground a notion of productivity that is based on generative and integrative aspects of conversation alone.

While Goldschmidt does not explicitly identify them as such, linkographs are essentially network representations.[82] Understanding Goldschmidt's measures of structure as network metrics opens the door to more elaborate network conceptions and methods, such as those I will describe later in this thesis.

Summary

The purpose of this chapter has been to lay the methodological groundwork for a systematic inquiry exploring the roles of persistent, shared external representations in design collaboration. Toward this end, I identified elements of structure, based on considerations of case study method, that will enable me to draw valid and meaningful conclusions from this single, exemplary case. These include the need for clear boundaries, appropriate units

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[82] I am indebted to Helga Wild for the observation that linkographs are a form of network representation.

of analysis, a conception of predictor and criterion variables and triangulation in analytically-meaningful interpretations.

Actual determination of these elements of structure depends upon specific features of each case, and on the overall objectives of the research. Accordingly, I will discuss each further in the following chapter, as I enter the field setting. The objective of this research is to gain an understanding of the ways in which communicative acts and representational activity are interwoven to accomplish the interactional work of collaborative design. This is a process of synthesizing perspectives, reconciling differences and consolidating collective commitment to a course of action to bring about a preferred future reality. Specifically, this research aims to highlight the active involvement of persistent, shared representations in collective design reasoning, and to develop a method for making this visible that can be applied beyond the context at hand.

Techniques and analytic foci for video interaction analysis suggest additional considerations. These include a distinction between micro and macro levels of analysis, utilization of participants' own segmentation of their activity, and close attention to trouble and repair as well as productive interaction. Case study analysis involves contrasting these as clearly and sharply as possible to afford theoretically meaningful interpretations. For this purpose, a number of observational coding schemes were reviewed. These provide resources for categorical distinctions characterizing both the content of design reasoning and the ways in which the process unfolds, including attributes of formal reasoning, constituent acts and mundane activities that comprise design conversations.

Design reasoning has aspects of both sequential progression and iteration, during which participants utilize various communicative modalities and external media. It involves frequent shifts—in the locus of discourse, between communicative modalities and in engagement with artefacts and representations. Productivity in design conversation also requires an essential movement and development that, in its topical specificity, escapes abstract or categorical formalism. This underscores the need to attend to the evolution and connectedness of discourse, as well as its categorical composition.

The productivity of design conversation is evidenced by the engagement and excitement of participants, as well as in the generative and integrative impact of their contributions. This study offers an opportunity to combine micro-level observation of communicative and representational activity with externally-valid assessment of outcomes and process quality, grounded in the context of an authentic design practice. It is also an opportunity to see which aspects of these observational schemes resonate with the way people actually work together—at least in the particular type of design activity I observe—and what other phenomena may need to be taken into account. These are the subjects to which I turn in the following chapters.