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Articulating (mis)understanding across design discipline interfaces at a design team meeting

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Abstract

Communication is both the problem and the solution to misunderstanding. It is the human communicative ability to display understanding to resolve misunderstandings that plays an important part in the organization of the design inputs to a construction project. Ambiguity and uncertainty, as different forms of misunderstanding, are studied in this article, as they are manifest in the conversation at a design meeting. In this setting the coordination of both *in situ* design activities and the planning of design tasks takes place in real time, in conversation. Exhibited are several ways that design ambiguities and uncertainties can be seen in the interactional details of a multidisciplinary design team's conversation, to then report on how different design expertise featured in the raising of, and attempts at resolving, the misunderstandings that arose. In the course of this meeting, ambiguity and uncertainty were observed not as neat, discrete phenomena but were interwoven in the conversation. This characteristic poses difficulties in the disambiguation of the problem-solving response to each form of misunderstanding and further develops our understanding of design as it is communicated and conducted in social interaction. Finally, some implications from this study are put forward to inform the design of support for collaborative design.

Keywords: Ambiguity; Conversation Analysis; Coordination; Design Meetings; Uncertainty

1. INTRODUCTION

Communications in the construction sector are notoriously complex (Higgin & Jessop, 1965). In the architecture, engineering, and construction sector (AEC) communication is conducted across numerous interfaces, in situations where the risks at stake are high and with high levels of uncertainty (Winch 2010, pp. 346–377). AEC complexities are in part a consequence of the organization of work, where the division of labor and the different specialist expertise that inputs into a project are in arrangements described as complex product systems, project based, and temporary multiorganizations (Hobday, 2000; Bresnen, 2005). Characteristically then, communications are across both discipline and organizational boundaries that are established for the duration of a project, to be reconfigured with other people and organizations on the next project. Under these conditions, the potential for misunderstanding is high, particularly at the design stage.

Although engineering is often described as a collective field (Pahl & Beitz, 1984; Dym, 1994; Petroski, 1994), there is specialization in the expertise within the engineering profession (Abbott, 1988; Chapman & Levy, 2004) and also in the specialist engineering expertise that is present in a construction project. Given this, a persistent concern when designing buildings is the negotiation of the designed attributes for a scheme as well as the coordination of the different design inputs to a project. The importance of collaborative working between disciplines is widely recognized along with the fact that organizational interfaces and project management practices are barriers that can impede smooth communication and shared understanding (Kleinsmann & Valkenburg, 2008; Maier, 2009; Ren, 2011). For example, examining communication in the management of projects, the very nature of coordination, is considered problematic (Coates, 2003, 2004), and in design teams, people were seen to orientate to their functional roles, since these are determined by their technical skills and knowledge (Foley & Macmillan, 2005). Notwithstanding these characteristics, the built environment that surrounds us, and the projects that do come to fruition, are testament that multidisciplinary design teams are able to negotiate the complexities of communication, at least to some

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workable degree. The study of how design teams do then overcome complex communicative situations is of interest to further understand how design teams communicate in both face-to-face interaction and in distributive working environments and also to inform the design of new systems and tools for collaborative working (Cross & Clayburn Cross, 1995; Cross et al., 1996; Pena-Mora, 2000; Austin, 2002; Demian & Fruchter, 2006; den Otter & Emmitt, 2008; McDonnell & Lloyd, 2009; Ivarsson, 2010; Luff & Heath, 2010; Donovan et al., 2011; Gu, 2011). To further these lines of inquiry, it is the communicative ability to display understanding and also attend to misunderstanding that plays a crucial part in how we coordinate the multiple design inputs to a project. In this article, it is the intricate ways that designers communicate their (mis)understandings across discipline interfaces at a design team meeting that are studied. In particular, it is the ways that ambiguities and uncertainties in the design of a project arise in the interactional details of a conversation that are examined. The purpose here is not only to reveal what is misunderstood in this episode but also to examine the ways that a multidisciplinary design team articulates and then attends to their misunderstandings: in the raising and problem-solving responses to the misunderstandings that arise. A point of departure from many previous studies is that conversation from a "live" project forms the data for this study, and this is reported and analyzed in fine-grained detail.

This article intitially introduces ambiguity and uncertainty as different types of misunderstanding, followed by details of the data materials and then the theoretical position that underpins this study. The analyses of the episode exhibit design misunderstandings in several forms, as these were manifest at a design meeting, to advance understanding of the ways that design is conducted and communicated and to provide insight for design support in collaborative work.

2. NEGOTIATING (MIS)UNDERSTANDING IN DESIGN TEAM INTERACTION

To discuss misunderstanding in conversation, we first consider the contra position, understanding. It is to the field of conversation analysis, in the way that natural language use is structured and analyzed, that we turn to explain this. Conversation analysis operates on the assumption that conversations progress on the intersubjective understanding of the participants as routine and that some "problem" or "troubles at talk" are marked by a structural change in the routine turn-taking system, and this takes the form of some "repair" (Sacks, 1974; Hutchby & Wooffitt, 1998). "In conversation analysis 'understanding' has become technical. . . . [S]peakers display in their sequentially 'next' turn an understanding of what the 'prior' turn was about . . . that is something that gets displayed in the next turn in the sequence" (Hutchby & Wooffitt, 1998, p. 13). Each time we take a turn in conversation, we indicate what we know and what we think others know (Stivers et al., 2011). Drawing on conversation analytic insight, misunderstanding is when there is intersubjective misalignment between speakers. It is important to this research that this can be observed in conversation, in the ways that the participants intersubjectively negotiate on a turn by turn basis what has been (mis)understood.

2.1. Characterizing ambiguity and uncertainty

Misunderstanding is not defined by Schrader et al. (1993) in their study of information processing in organizational design; however, they understood that ambiguity and uncertainty are different types of misunderstanding that have different characteristics. *Uncertainty* "is characterized by a lack of information" (Schrader, 1993). This definition was informed by Galbraith's (1974) recognition of differences between the information an organization has and the information it needs. In short, uncertainty is a missing information problem. An *ambiguity* "is characterized by a lack of clarity" (Schrader, 1993) and includes the existence of multiple and conflicting interpretations of a situation (Daft & Lengel, 1986) and where a single item could mean one thing or another (Jefferson, 2003). The concept of ambiguity acknowledges that words in our conversational use of language can have multiple meanings and that a sequence of words can be interpreted differently.

Different types of misunderstandings lead to different kinds of technical problem-solving actions (Schrader, 1993). The problem-solving response to ambiguity is to redress the interpretative ambiguity. The problem-solving response to uncertainty is to take actions to address the missing information. From this insight, design situations can be considered both uncertain and ambiguous, as although the design of a building is a likely outcome, the form and characteristics of a yet to be designed scheme are not yet known in the process of design. In short, we engage in design in situations where what is being designed is not fully known and clear and also the information needed to design this is not completely available. This complexity is exacerbated by the structure of AEC project organizations where the expertise to make design decisions and produce information, and thus resolve misunderstandings, resides within the project organization, yet in this organizational structure the coordination of cross-functional resources is weak (Hobday, 2000). Contingent actions are acknowledged as part of this project work. This involves making choices in actions and trade-offs in situations of incomplete knowledge and when the consequences of actions cannot be fully known in advance (Pich et al., 2002). In theory then, a project organization is attentive to conditions of ambiguity and uncertainty. In practice, and in the situated response to events at any one moment in time, actions are not always attuned to differences between ambiguity and uncertainty. Design work undertaken in project teams, as we will see, is no exception.

2.2. Ambiguity and uncertainty in design

Design studies increasingly acknowledge that coconstruction happens in design conduct, that is, where a problem and a solution are considered to coevolve in the course of the design

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activity (Maher et al., 1996; Dorst & Cross, 2001; Reyman, 2009). This reframing of design, as an emergent problem–solution activity, although different from rational problem-solving models, does not contradict with Schrader et al.'s (1993) characterization of ambiguity and uncertainty. Problems are not characterized by inherent levels of ambiguity or uncertainty but in the problem-framing process (Schrader, 1993) and has been examined in the logic of design conversation (Dzbor & Zdrahal, 2002).

It is also known that design communication often fails to understand the nature of different forms of misunderstanding (Stacey & Eckert, 2003). More specificity in *what* is ambiguous or uncertain needs to be expressed as clearly as possible. Ambiguity, when there is an interpretation in two or more distinct ways, is sometimes viewed favorably when designing (Bucciarelli, 1994, pp. 113–114), although not always (Eckert et al., 2003). Uncertainty can include vagueness and imprecision and is observed in some design settings (Glock, 2009). For example, sketches can communicate provisionality under specified design ideas, and their ambiguity can be viewed as potential for reinterpretation in the development of design ideas (Eckert et al., 2003). There can be ambiguity when there is insufficient precision in a drawing and a need to understand how much of what is not shown (on a representation) is fixed. Moreover, differences between the clarity of the current design situation and the detailed exactness of the design information available are problematic. Attentive to this, Clarkson et al. (2000) proposes that engineers state the degree of completeness, or formality of information, using initial estimates, feasible estimates, and final values as categories to clarify judgment statements of imprecision and provisionality. When designers meet in person, this provides a setting where in conversation various ambiguities and uncertainties can become apparent and where intersubjectively misunderstandings can be addressed. Evidently communication is both a problem and a solution to (mis)understanding.

2.3. Design team meetings and task management

Design meetings provide a setting for the design team to communicate and are significant events on construction projects for several reasons. They are organized events, planned for a date in advance when a design team meets, in this research, in person. They act as milestones on a project, because minutes from a meeting set deadline dates for the completion of actions (e.g., setting deadlines for information). However, to view design coordination meetings solely as task coordination events, where plans are made for activities that will happen after a meeting, underrepresents what goes on in design meeting settings (Suchman, 1987; Ikeya et al., 2010). A characteristic of meetings where the design team is present is to discuss and progress a scheme's design *at* the meeting. At a meeting, progress also includes arriving at a better-shared understanding of a design situation.

To improve the ways that we understand design communication and then provide support to design teams, it would be helpful to be able to disambiguate task management actions from others, including resolving ambiguities in interpreting the design. It is Schrader et al.'s (1993) framing of distinctions between missing information (uncertainty) and when there is lack of clarity (ambiguity) at a design meeting that has potential in the study of this. Potentially, if we can locate instances of ambiguity and uncertainty empirically in design conversations, we can develop understanding of how technical problem-solving actions can be disambiguated and ways to provide support for this. Details of how this is explored are presented.

3. BACKGROUND TO THE DATA

The materials on which these observations are ground were gathered from a multidisciplinary design practice based in the United Kingdom, which provides consultancy services to the AEC and major infrastructure sectors internationally. The nature of the study was ethnographic, with the research team gathering data, video-recording meetings, and observing and making fieldnotes of activities as they took place in workplace settings over a 6-month period.

The design of one project was shadowed in particular, studying the activities of a design team longitudinally as the design of the scheme progressed. An advantage of this approach was that the flow of the scheme's design is reflected in the data collected, and it is possible to trace design issues raised but not resolved at that point in time in later design conversations. The researchers were present as participant observers at the planned design events, recording and collecting data but not contributing to the conversation. The data is regarded as naturalistic, in the sense that the activities on a "live" project are reported and that the events observed would have taken place regardless of whether the researchers were present.

The design team was multidisciplinary, and for the project shadowed, the same firm employed each of the design disciplines. A characteristic of this data is that it represents the practices and organization of design work of an interdisciplinary design team within a multidisciplinary design organization. This permits specific focus on the study of communication practices at the design discipline interfaces, without interorganizational boundaries complicating the picture. The research team has a rich body of data to draw from, including discussions with designers at work in the studio and the video recordings of the conversations at meetings, which are available for repeated viewing. Given the characteristics of this data, in theory the interdisciplinary design communications were unimpeded by interorganizational boundaries, in a deliberate attempt to overcome design discipline silo thinking. In practice, this data provides ample instances that exhibit design misunderstandings at the design discipline interfaces within a project organization.

The conversation selected for close analysis was chosen as it demonstrates how several design misunderstandings were manifest in a meeting setting, in this case at a design coordination event. These meetings were chaired by the in-

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house design manager (DM) and attended by the lead designer from each of the design specialisms for the project. The people present had pens and notepads and copies of the last meeting's minutes, which are materials that are routinely associated with attending a meeting. Seldom were design drawings brought to a design coordination meeting, and no drawings were brought to this event. Design coordination meetings were held on a weekly basis, for RIBA Stage C of the project. At this stage, the concept design and outline proposals for structural and building services systems were being prepared. The coordination of the multiple design inputs to the project were crucial at this stage to progress the design of the scheme.

In the selected extract, the interplay of different disciplines in the discussion of design misunderstandings is evident in a brief conversational sequence, which is reported verbatim (on other occasions misunderstandings emerged and unraveled over longer conversational sequences, sometimes spanning several meetings). The episode is defined by shifts in the topic of conversation, through the actions of the person chairing the meeting and with reference to action points from the previous meeting's minutes. The sequence ends when the chairman shifts the topic of conversation to the next action on the minutes.

4. METHOD AND APPROACH

The theoretical and analytic orientation for this research is informed by ethnomethodology and early work in the organization of talk in conversation analysis (Garfinkel, 1967; Sacks, 1992). Analytic emphasis is placed on the sequential order of talk, where what is said and what is said next are remarkable in exhibiting the practical reasoning of the participants. The local matters of the participants can be seen in their orientation to an immediately prior action, to what has just previously been said and done (Sacks et al., 1974; Schegloff, 1992; Koschmann, 2011). Sequential turns at talk provide a witnessable account of how the (design) work is accomplished on a moment-by-moment basis and how these participants orientate to their design discipline categories. The kinds of actions that are studied are the routine conversational mechanisms used in everyday interactions: the organization of turns at talk, and the order and the sequence in which things are said and done, including acknowledgements of mutual orientation to the task at hand that exhibit intersubjective (dis)alignment and (dis)agreement with others. These actions provide ways of accounting for how misunderstandings are raised and resolved. The progression of the conversation is studied in fine-grained detail to show how sequential actions change these designers' understanding of the design situation on a moment-by-moment basis, using a simplified version of the transcription notation developed by Jefferson (2004). Conversation is reported in sufficient detail to show the speakers' latched and overlapping speech and to report speech that can be heard but is not responded to. The people present at the meeting are an in-house DM chairing the meeting, a structural engineer (Struct), a mechanical/electrical services engineer (M&E), the project architect (Arch), and a BREEAM consultant.

5. ANALYSIS: MANIFESTATIONS OF DESIGN AMBIGUITY AND UNCERTAINTY

The episode we examine begins as the DM shifts the topic of conversation, with reference to the previous meeting's minutes, to the discussion of the plant room. The DM asks the question "Is that ready, do we have plant room sizes?"

Extract 5.1. "Do we have plant room sizes?"

1 DM:	ok (.) next action on here was uhm (.) plant room
2	sizes is that ready (.) do we have plant room siz[es
3 M&E:	[it's
4	not called a plant room(.)
5 DM:	we have an energy center (.)
6 BREEAM:	it's actually an ESD knowledge center=
7 DM:	=ok (.) I stand corrected (.) I do apologize (.)
8 Arch:	I[f we u:h try'n decide]
9 DM:	[I don't know this ter]minology (.)
10 M&E:	we got no problem whatsoever with numbers (.)
11	which are essentially [as drawn

The response is not an answer to the question; instead, the M&E designer asserts that "it's not called a plant room." Immediately we see the M&E designer is doing something other than answering the question, introducing some delay, which may indicate trouble in answering this (Hutchby & Wooffitt, 1998, p. 61). The M&E engineer's response reformulates the terminology associated with this building element, which is routinely called a plant room. The designer manager then self-repairs stating that "we have an energy center." The ambiguity noted at this point in time is in the interpretation of the terminology for this element of the building. This is not resolved as the BREEAM adviser adjusts the terminology again, volunteering, "it's actually an ESD knowledge center." The DM acknowledges this, "I stand corrected, I do apologize, I don't know this terminology." The DM, the M&E consultant, and the BREEAM adviser display what pragmatically seems to be some lexical ambiguity, referring to the same building element but using different terms. The actions of the architect can also be considered to support this "if we try'n decide." Seemingly, the name for this part of the building is a matter of choice. In good humor, the terminology for this building element became a topic of conversation. An answer to the initial question, whether the plant room sizes are available, is provided at the end of this sequence by the M&E designer, "we got no problem whatsoever with numbers, which are essentially as drawn."

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This brief sequence demonstrates several things. The sequence in which aspects of the design were discussed at this event was contingent on actions at the previous meetings and how these tasks were recorded in the minutes. The DM was organizing the major shifts in the topic of conversation with reference to the minutes. The minutes acted as a shared point of reference to actions at a previous event and also as a resource to organize this meeting. With reference to the minutes, the DM chairing the meeting was organizing the meeting in response to both premeeting events (a now previous understanding of the status of the design) and the flow of the conversation at this event. Different interpretations in the terminology for this building element became a topic for conversation. In a light-hearted manner, interjecting humor into the conversation, several permutations of reference to the plant room/energy center were used. These actions were consequential not only for the resolution of the interpretive ambiguity at that moment in time but also for some shared understanding of the project terminology, which will be relevant to this design team beyond this event.

The uncertainty, whether the plant room size information is available, is the initial question the DM raised. The eventual response is that the plant room sizes are available, "essentially as drawn." Drawings were not brought to this meeting, but seemingly this information is already provided on the drawings. The uncertainty in the plant room information seemingly is not a problem delaying the design of the project, since the M&E engineers says: "we got no problem whatsoever with numbers."

Extract 5.2. "We got no problem whatsoever with numbers"

10 M&E: we got no problem whatsoever with numbers (.)
11 which are essentially [as drawn
12 Arch: [we draw it that size an
13 we just gott'uh see how it crunches out I
14 know the SF project have managed to (.) cause
15 it's an ecocenter (.) not include it in the
16 area but that's chea[ting a bit
17 M&E: [hehh hahh h[ehh
18 Arch: [so I'm (.) I'm
19 not s:ure if we can do that here or not at
20 least it's within the buildings (.) gives us a bit
21 more flexibility
22 DM: ok (.) what about other areas within buildings (.)
23 are there gonna be any other areas(.) or is it
24 literally a:ll i[n the] center and then (.)
25 M&E: [u::hm]
26 DM: distributed from there (.)

To some degree, the architect is satisfied that the energy center will be designed to the M&E engineer's sizes, "we draw it that size and we just gott'uh see how it crunches out." The architect makes known the contingencies in his way of working interdisciplinarily, where the information that he uses to design are connected with the actions of other design disciplines. The architect then references another project, and recounts that the SF project was able to "not include it in the area" calculation because it was classed as an ecocenter. The architect does not know "if we can do that here . . . at least it . . . gives us a bit more flexibility," marking an epistemic ambiguity, which may also be an uncertainty that could be resolved with information that is not currently available, to establish whether this element can be classed as an ecocenter on this project. However, how the size of the energy center affects the calculation of the total area of the building is not known at this point in time. In the progression of the conversation so far, it is evident that a shift in conceptual understanding of this building element as an ecocenter rather than a plant room has broader consequences for the scheme. It is now apparent that the term used to reference this building element is not merely a matter of lexical choice. The participant's renaming of the plant room/ecocenter was indicative of interpretative ambiguity that is also linked to uncertainty in the classification of this as an ecocenter and then to the calculation of floor area for the scheme. The ambiguity in terminology and its uncertain effects on the calculation of the floor area evidently were not discrete misunderstanding problems. Next the DM seeks additional clarification on the services design and asks the M&E engineer, "What about other areas within buildings . . . Is it literally all in the center and then distributed from there?"

Extract 5.3. "All in the center and then distributed from there?"

26 DM: distributed from there (.)
27 M&E: what we actually did originally (.) we actually
28 provided all the figures (.) on the assumption
29 that the court option was gonna be the one (.)
30 we also indicate storage areas in each of the
31 buildings which are gonna be required for
services or
32 which are gonna be distributed in
33 an underground sy[stem
34 Struct: [all underground (.)
35 M&E: yes (.) y'gonna go underground (.) got a
system
36 of pipes runnin. (.)
37 Struct: what's that within or is that just between the
38 buildings (.)

The M&E engineer's response accounts for some of his design assumptions: that the courtyard option would eventually be developed and that there will be storage areas within each building. The M&E services "are gonna be distributed in an underground system." The Struct interrupts and asks whether all the services will be buried "all underground?" The M&E engineer answers "yes" and then elaborates on the details, "y'gonna go underground, got a system of pipes running." Again the Struct interrupts the M&E engineer's incomplete turn at talk with another question "what's that within or is that just between the buildings?"

In this sequence we see that a conversation that starts with one question leads to further questions. The Struct requests

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more specificity in the M&E design solution and the configuration of the building services, whether this will be underground and solely within or also between the buildings. We begin to get a sense of how through sequential turns at talk possible permutations in the design of the services are raised, answered, and then lead to other questions. In this way the Struct's understanding of the services design becomes increasingly more detailed, in response to the questions he raises. Other members of the design team overhear this too and are party to the design insights offered. Through sequential actions, where one point built upon another, it is apparent that a form of design coordination is taking place at this meeting: thus raising the team's awareness of some design assumptions, in being able to respond to these, and in this way their knowledge of how the scheme will be designed is extended. This was happening in the conversation and without access or reference to design drawings.

Extract 5.4. "Within or is that just between the buildings?"

37 Struct: what's that within or is that just between the
38 buildings (.)
39 M&E: it'll be between the buildings yeah=
40 Struct: =really ok
41 M&E: what's wrong with that you've forgotten about
42 it=
43 Struct: =n::o yo- just (.) y'gotta get down through and
44 back up again and then down (.) it'll be a (.)
45 pain (.)
46 M&E: why
47 Struct: we'll gotta have'em in the building ain't ya (.)
48 down below the ground (.) up'n down (.)
49 s'gonna ve'em with pits un. pits'n chambers
50 an all sorts of things (.) they've gotta be
51 water tight (.) all sorts of things
52 M&E: n:::o don't worry about it (.) what we've
53 actually got (.) in order to supply this
54 and help you guys out (.) instead of having
55 a deck of services (.) build a service
56 trench in the ground

In response to the Struct's question, the M&E engineer answers, "it'll be between the buildings," The Struct's response, "really," indicates surprise and also raises doubt, followed by "ok," which is indicative of some form of acceptance. The M&E engineer next responds, "what's wrong with that," making it known that he has noticed the Struct's doubt, and continues, "you've forgotten about it?" and thus marks a shift in who is asking questions. These actions make it conditional on the Struct to account for why underground services between the buildings might be problematic. The Struct first answers "no," acknowledging that has not forgotten, and then elaborates why, in his view, this design configuration for the M&E services is problematic, "y'gotta get down through and back up and then down, it'll be a pain." The M&E engineer's next question challenges this, "why," making it conditional on the Struct to provide further explanation. The Struct elaborates on the design consequences, "in the building . . . below the ground . . . pits and chambers . . . water tight all sorts of things." The design of the structure for this part of the building is becoming more complex.

We see that what is viewed as problematic for the Struct is not seen as complex for the M&E engineer, who then makes his disagreement known, "no." The M&E engineer continues, "don't worry about it" then elaborates on the services "to supply this and help you guys out," and in saying this acknowledges that there are interdependencies between the design decisions these engineers make and that he is attentive to this. The M&E engineer proposes that "instead of having a deck of services, build a service trench in the ground." In these actions the M&E engineer makes it known that the design will include a service trench, which he acknowledges has implications in the design of the foundations, but considers that this helps the Struct. The M&E and the Struct now openly disagree on how problematic this design solution is and through reasoned accounts bring other factors, "pits'n chambers" and "water tight," into this debate. This is a contested design territory that affects both of these engineering disciplines.

In the progression of this conversation, we have reached a momentary design state where we now know that underground services will be both within and between buildings. Evidently this was new news for the Struct. This extract also reveals a disagreement between these design disciplines concerning the proposed design solution and further consequences. Seemingly the M&E engineer does not anticipate the buildability complexities in the ground works as the Struct does (at a subsequent meeting the on-site difficulties constructing the foundations on another project are recounted). In the course of this conversation, the M&E engineer provides additional detail in how the services will be designed. At this point in time, we do not know whether this information is already on a drawing (evidently the DM and the Struct have not seen this if it is) or whether the M&E engineer is ad-hocing. In other words, he is improvising in the conversation, making known what he has in mind and how he intends to design the services but has yet to prepare the drawn project information. Evidently, design meetings provide a setting where what is planned or intended in the design can be expressed. Revealed at this meeting was a situation of either incomplete information or asymmetrical design insight.

Extract 5.5. "A deck of services"

55 M&E: a deck of services (.) build a service
56 trench in the gro[und
57 Struct: [y::eah=
58 M&E: =y'gonna have a service system (.)
59 Struct: right just=
60 M&E: and=
61 Struct: =just a pipe (.)
62 M&E: in effect what y'gonna have are two loops (.)
63 feeding or collecting to the ecocenter (.)
64 and from there y'gonna have a pipe going into

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65 each of the buildings (.)
66 Struct: in one building (.) drop it in the floor out
67 under the ground beams in the ground then pop
68 back up in the (.) corner of the other building
69 (.) do we know what room or space it's in=
70 M&E: I mean there's gonna obviously be provision for
71 storage cupboards which will go on the outside of (.)
72 each
73 DM: in each of the blocks effectively (.)
74 Struct: sounds like you'll have two (.) one in one out
75 in each corner=
76 M&E: what you have to basically do is (.) look at the
77 mechanical layout (0.2)
78 DM: that's something you'll need to bring to the
79 table on Friday (.)
80 M&E: ok

We rejoin the conversation as the Struct acknowledges, "yeah" there will be a service trench in the ground. The M&E engineer then elaborates that "y'gonna have a service system." The Struct then asks for further detail, "just a pipe?" The M&E engineer uses the future tense to describe how this will be, "what y'gonna have are two loops" to connect the eco-center to the other buildings. The Struct asks where these pipes will enter the building, "do we know what room or space it's in?" and in the M&E engineer's response he makes known his assumption that there will be service cupboards on the outside walls. The DM then builds on this assumption, "in each of the blocks," and the Struct adds, "sounds like you'll have two" (feed and return pipes). In this way, both the DM and the Struct formulate implications from the M&E engineer's design of the services. The Struct's actions expand on details of the services, exhibiting some understanding of services design, and these are actions that potentially encroach on M&E expertise. The M&E engineer neither agrees nor disagrees with these assessments, his response is "you have to . . . look at the mechanical layout." Seemingly, he implies that this information is already available on the drawings and it is their oversight in not looking at this. However, the DM's next action is remarkable as he says, "that's something you'll need to bring to the table on Friday." This action makes it known that this information is not yet available, to the DM's satisfaction presumably, or to the design detail now needed.

In this sequence the Struct and the M&E engineer engage in more detailed discussion of the specifics of the services design and while doing this a switch to the future tense, to describe "what will be," is noted. In the course of this conversation, the participants' understanding of the services design has progressed beyond what is represented on the M&E drawings and also beyond what was known about this before this meeting started, as incrementally their appreciation of the design situation evolves. The missing services design information is now marked as an action for the M&E services engineer to redress after the meeting.

Extract 5.6. "How do you maintain this pipe?"
80 M&E: ok
81 DM: uhm (.)
82 Struct: how do you maintain this pipe the (.) it's in the
83 ground for=
84 M&E: no it's for twenty years (.)
85 Struct: =sixty-five years
86 M&E: yeah (.) if it's for sixty-five years
87 then all we have to do is increase the size and
88 reduce the temperatures (.) cause polyurethane
89 is capable of fluctuating over a wide range (0.2)
90 Struct: it just gets buried in the ground and that's it
91 (.) fine
92 DM: ok (.) movin on (.) the action on the flood risk

The M&E engineer's response "ok" is an acknowledgement, agreeing to the DM's request for this information. This is a remarkable juncture in this conversation, because it marks the M&E engineer's acknowledgement that this information was not yet available to the detail that the M&E services were described here, although evidently an M&E drawing was already available, since the M&E engineer referred to this to deflect further questions on the services design (e.g., "look at the mechanical layout").

The Struct persists in questioning the adequacy of the services design solution, "how do you maintain this pipe?" The M&E and the Struct have different interpretations of the life span of underground service components, and they eventually agree that a 65-year component life span is adequate for a buried pipe. The DM then shifts the topic of conversation, "ok, moving on, the action on the flood risk." The DM is seemingly satisfied that the discussion of this aspect of the design (plant room sizes and services) has reached some conclusion. In design management terms, the M&E engineer has now acknowledged that some information was missing and has agreed that this will be available by Friday. In terms of design task management, the assignment of responsibility to produce this information has been agreed and a date has been set for this.

Here we see that the management of face featured in one designer's attempt to refute that their information was missing and was potentially causing delay to another design discipline. At times there was encroachment, blurring the boundaries of fields of engineering expertise. Actions such as these are not entirely surprising, since engineers are aware of the interrelated nature of their design work and with experience in practice become attuned to how the design decisions they make are consequential for other disciplines, and in conversations such as this they display an attentiveness to this (e.g., "help you guys" knowing that underground services affect the design of foundations). Design meetings like this can in several ways be considered pedagogical: The designers present learn more about the scheme being designed than is cur-

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rently represented on drawings, as they describe what will happen and negotiate how this is consequential for their interrelated design work. In this process, they garner insight into other disciplines' design thinking. The participants offer specialist design input into problem finding and solving, and over time, patterns in the likely problems and solutions to similar problems are overseen and, to some degree, are learned. This overseeing of another discipline's design reasoning is enabled through the organization of meetings where communication occurs across discipline interfaces.

Notwithstanding the remarkable design insights and accomplishments that were revealed, in the course of this conversation the architect's point concerning the consequence of the size of the energy center in the calculation of the building's floor area remains unresolved. It was an interpretative ambiguity, whether this can be referred to and classed as an ecocenter, as well as an uncertainty that could be resolved with further information. It was also a decision that is majorly consequential for the viability of the scheme. This was embedded in this conversation, yet it remained unanswered and was not noted as an action to resolve with additional information after the meeting.

6. DISCUSSION

Design meetings are a perspicuous setting to study the ways that understanding and misunderstanding are manifest in the progression of the design of a building. In this study we are able to be more specific and demonstrate the ways that several design misunderstandings featured in this conversation and the interplay of design expertise in this. Misunderstandings of both an ambiguous and an uncertain nature were evident. It was how these were articulated in the flow of the conversation that is of interest.

6.1. Design meetings as ordered events

The conversation at this meeting was observably ordered, for example, in the managed shift in the conversational topic to the plant room and also in the speaker turn-taking system, often in question and answer sequences. Examining this sequence, the overarching organization of the meeting was in the shifts of topic of conversation by the DM, with reference to an agenda. At a more detailed level, within an agenda topic, the transfer of turns at talk was self-organized on a turn by turn basis. The designers were self-organizing the discussion of aspects of the design that needed specific design expertise and addressed their questions to the relevant person, often the M&E engineer. What was seen was not random topic discussion but highly ordered and attuned actions, where a next turn built on what had just previously been said to pursue a line of design inquiry.

6.2. Misunderstandings interwoven in the conversation

The design ambiguities and uncertainties observed in this conversation were not so neatly organized. Misunderstandings were not observable as discrete particles of speech or in single turns at talk. It was in the course of conversation, in and through the shifts in the designers' display of understanding over several exchanges, that the misunderstandings were manifest. The design misunderstandings in this setting were interwoven in the conversation as it progressed. It is this characteristic that is noteworthy.

The participants intersubjectively negotiated their (mis)understandings in the course of the conversation. An interpretative ambiguity, concerning the design of the services, was raised on occasion in question and answer sequences, and the next response addressed the query. At other times, when a response did not answer a question to a person's satisfaction, a follow-on question pursued a response in more detail. In this we see naturally occurring conversation at work, where as communicators we are adept and in our spoken language use have the conventional mechanism of turn taking to follow up on lines of inquiry. However, a response did not always resolve the ambiguity in the services design. In addition, what was then known and understood about the services changed, and this new insight led to further questions. The designers' understanding of how the services "will be" shifted on a moment by moment basis in the course of the conversation. Although some specific detail of the services was revealed and made known in a turn at talk, an ongoing ambiguity in this episode was the interpretation of the services design and implications in this more holistically, and this was revealed over a sequence of exchanges. The ambiguity in the services design was intricately intertwined in the course of the conversation and also interlaced with other misunderstandings (e.g., whether a drawing was already available with this information and how the plant room area would be calculated). Misunderstandings of an ambiguous and uncertain nature were seen to be ordered in the turn-taking structure of conversation, but they were not neatly organized as discrete topics or particles that were "resolved" in sequence.

The manifestation of misunderstanding in this conversation is viewed analogously with the ways that we understand design as coevolving and problem-solving activities. The ability to locate a discrete design problem, and then a design solution, is easier in some situations than in others. It is the reframing of design as the coevolution of a problem–solution that provides a more apt characterization for how misunderstandings were embedded in this conversation. Here misunderstandings were seen to be local, discussed at a specific point in a conversation, and also were contingently evolving in the progression of conversation and some had implications that extend beyond the meeting setting.

6.3. Interdisciplinary design interfaces

Design communication in this setting was studied across the discipline interfaces within an organization. This way of working may address some, but evidently not all, design interface issues. The meeting provided a setting for the known design complexities to be discussed and different design ex-

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pertise to collaboratively negotiate aspects of the project's design in real time. It was seen to be an important setting to debate the design solutions proposed and also their consequences. The need to coordinate the M&E and the Structs' expertise in the design of the plant room and the distribution of M&E services throughout the scheme was the predominant topic of conversation. The problem whether the services would be buried in the ground both within and between buildings was interwoven with the problem of the foundation design. Interpreting the consequences of the proposed design solution was also problematic. The M&E engineer and the Struct were seen to draw on specific expertise to consider the design consequences of the ideas proposed. The Struct was able to preempt further complexities, in on-site work with "pits and chambers," as well as with adjustments that were needed to the design of the foundations. This ability to think beyond his immediate structural needs is considered to demonstrate that at times his orientation extended beyond a functional role. In this extract, the notion of people speaking for a design specialism was relevant but also underrepresents the understanding of the situation displayed. Engineering expertise, especially in the area of energy production and consumption, is responsive to change. The presence of a BREEAM consultant in this setting and the discussion of the energy use consequences of the scheme illustrate that the design disciplinary interfaces within a project are increasing in complexity. Organizing design events where people meet and talk can help by providing a communicative encounter to articulate these complexities.

6.4. Designing *in situ*, in real time

The human capacity to intersubjectively understand is accomplished with a range of communicative and cognitive resources. It was seen that in the raising and sometime resolution of misunderstandings in this setting, the participants did work toward some shared understanding of the design situation. As Stacey and Eckert (2003) have noted, Although absolute shared understanding is necessarily incomplete, humans are adept at achieving sufficient shared understanding to meet their own needs. Observably at this meeting the modification of the design was happening verbally, in real time. The M&E engineer demonstrated accomplished skills in improvising in the moment to make known aspects of the services design.

The design was modified in conversation, but the state of the design at any moment in time was ephemeral in the minds and discursive space of the participants. There was no physical record of this change in understanding or material change, say, to design drawings or to a building information model. It is the real-time shifts in a speaker's understanding at that moment in time that were evident through examining the progression of the conversation in the close detail required with this method. The designers' understanding of *what is known* was evident in *what is said*, and this resource is available to us as researchers retrospectively and to the participants at the time, as this was happening. In what was said and what was said next, the speakers intersubjectively negotiated their understanding of the situation and displayed this in their conversation. Because the design of this scheme was discussed in a team setting, it was not only the person who raised a design issue who became aware of its consequences but also those listening.

In the account presented, it was seen that designing was happening at the meeting, in the discussion of what will be or might become. The design solutions proposed were yet to be represented graphically. However impermanent these ideas were, they did change the participants' understanding of the design of the scheme, and other ambiguities and uncertainties were then raised.

6.5. Planning design tasks

Design meetings are routinely viewed as events where the team discuss project progress and negotiate the design of a scheme. The DM was seen to disambiguate an information uncertainty from other misunderstandings and then set a task to be completed after the meeting. This is routine practice at meetings and in the management of a design project. This was contingent on his understanding of the situation, following the progression of the conversation as it happened in real time. However, not all misunderstandings were resolved or noted as an action, even one majorly consequential for the project was to some degree overlooked. Ambiguity in the terminology for the plant room, and its consequences, was not noted as an action. This illustrates that, although understanding was displayed on a moment by moment basis, in the course of this conversation some problems were lost.

7. IMPLICATIONS FOR DESIGN

Through close inspection of the conversation at a design team meeting shows several ways that misunderstandings were manifest in this brief episode. Ambiguity and uncertainty in this sequence were seen to be not neat and discrete entities but were interwoven phenomena. The ambiguities and uncertainties observed were embedded in the course of the conversation and in a design situation as it was unfolding. The misunderstandings revealed here were not evident in easy to locate conversational structures but semantically in problem-solving actions and design reasoning across turns at talk. This characteristic poses difficulties in the disambiguation of the problem-solving response to each form of misunderstanding and further develops our understanding of design as it is communicated and conducted in social interaction and what this in turn implicates for the design of support for collaborative design.

7.1. New insight into design communication at meetings

This research reveals new insight into the multiple purposes for design meetings and how the resolution of different types of misunderstanding were important for different people that, in turn, led to different actions. At this meeting, understand-

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ing the current status of the design was problematic, since the services design was being modified verbally and new, increasingly detailed insights to the mechanical services were provided. This was an ongoing ambiguity, which involved interpreting the design consequences in what was being proposed in the moment and then with this new insight making any consequences and concerns known and shared with others.

In an overly simplistic way, this episode can be glossed as a meeting to highlight missing information. The conversation predominately involved attempts to discuss the design working around missing mechanical services information. A parry ongoing at this meeting was who was responsible for this missing information: Was it the M&E engineer's delay in producing this drawing, or was it the Struct and the DM's fault in not looking at this beforehand? The M&E engineer eventually admits that this information is not yet available, to the detail required, and then agrees to prepare this. Had this information been available, arguably, many of the questions raised need not have been asked.

However, to view this missing information as a mistake (poor design management or the underperformance of an engineer, etc.) would misunderstand a key purpose for design meetings and also lack an appreciation of the nature of design work in multidisciplinary teams. Design is ongoing in situations of incomplete knowledge and information. This meeting was about more than checking whether design information was available, although this was happening here and was a prime concern for the DM. Although this evidently was a meeting held to manage the design tasks of the team, for their activities to be coordinated and for one design discipline not to delay another, this was not the only thing happening at this event. What was going on in the discussion of the missing information can be viewed more constructively. It is because this conversation happened in a team meeting setting where actions are overseen and overheard by others that the intersubjective understanding of the multidisciplinary team was heightened.

The questions the DM and the Struct asked were not an outright challenge on the M&E services design but information-seeking questions, pursuing further detail in the services design. The Struct's questions can be considered to be tactical, because they unpacked what the M&E engineer already knows about the design of the services to reveal aspects of the scheme that were not yet known to the Struct. The Struct's questions were not out of curiosity but were integral to his design work.

Raising questions at a meeting, which prompted expressions of intent in how the M&E services *will be* designed, brought the design of the services into a shared discursive space permitting multidisciplinary design input on this. The Struct made known some implications and consequences contingent with the proposed design solution, and we saw that the M&E and service engineer were not always in agreement. In this way, the services design ideas were discussed before a solution was more formally represented (on a drawing or a building information model). Furthermore, this was a debate that was overheard by the design team. We saw that, working in a discursive space, the engineers were able to improvise in the design of the services. Evidently, this was a conversational setting that permitted a continent way of working, where exploratory thinking and articulating how the services might be was possible, as well as providing accounts of how the scheme has been designed.

Had this meeting been held solely to report on missing information, to then assign task responsibilities to produce this, arguably this could have been conducted more efficiently with reference to the drawing repository, potentially with an automated message system to flag responsibility for outstanding information. The need to meet in person would then be reduced. Evidently, meeting in person more was accomplished than this, and it is considered that what happened in the coordination of the design in this setting taps into the essence of design work in multidisciplinary teams. In this exchange we saw the raising and the sometime resolution of design problems in real time, which were remarkable design coordination accomplishments.

7.2. Implications for systems design

Insights from sociological perspectives on communication and natural language use increasingly underpin information systems design. The increase in conversation analytic-informed computational linguistics does indicate a movement to reveal what people actually do in conversation. For example, McRoy and Hirst (1995) uses "repair" to model how misunderstandings lead to unexpected actions. Stolcke et al. (2000) locate conversational "continuers" to probabilistically improve the classification accuracy in speech recognition and in Jurafsky's (2004) cue-based probabilistic computational linguistics. These studies all point toward the relevance of natural language use as a resource for computational linguistic, speech recognition, and natural language processing purposes, and their potential to then inform systems design. Although there are substantive inroads in the application of conversation analysis as part of systems design, it is also suggested that the potential for automated searches, machine learning of conversation analysis' "rules for speaking," is somewhat limited (Button & Sharrock, 1995). The "rules of speaking" are considered to be different from how computers use rules. This debate is active in several research fields that are evolving rapidly.

As researchers with access to review the conversation at a design meeting, this furnishes us with privileged insight into the communication practices of these designers. The analyses presented were not fully detailed conversation analysis; however, they do point out several characteristics of design communication in this setting that are of interest in the development of design support. The identification of missing information (uncertainty) as distinct from the lack of clarity (ambiguity) may have potential in the disambiguation of technical problem-solving responses. While interpretative ambi-

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guity, to understand the in-the-moment design situation was happening continuously, it is the potential to locate instances of missing information that arise in conversation that may have more traction. Drawing on insight from analyses with a conversation analytic orientation, we can consider some of the challenges that arise in the design of support.

"Repair" in conversation takes several forms and is structurally locatable in conversation. It is routinely used to study misunderstanding and on occasion to study ambiguity specifically (Jefferson, 2003). When conversation analysis is applied in the field of computational linguistics, "some input is *ambiguous* if multiple, alternative linguistic structures can be built for it" (Jurafsky & Martin, 2008, p. 4). Potentially then it is analytically feasible to locate a misunderstanding in conversation. In the episode examined, however, instances of repair were only partially helpful to locate the misunderstandings observed. Furthermore, it was not structurally possible to disambiguate uncertainty from ambiguity in way that Schrader et al. (1993) defines these through the analysis of repair.

Question and answer sequences were characteristic of many turn-taking sequences in this conversation, and the location of this structural mechanism, if this is possible to automate, may have potential. The ability to parse conversations by speaker in the course of a conversation would need to be attentive to a speaker's changed position response to different but semantically similar questions, as was observed. It is the M&E engineer's different response to the missing services design information that comes in mind. Disambiguation that is able to recognize a speaker's different position and views expressed at different points in time is needed: to be able to disambiguate the engineer's initial responses, which claimed that the information was already available, from the position ultimately reached that although an M&E drawing may be available, this did not resolve the missing information needed now. This is a routine characteristic in design, where information is needed in increasing detail as a project progresses. Design information is characteristically not produced in some absolute sense (drawing available or not) as the content of the drawing comes into play. This may sometimes, although not always, be evident in the name of a drawing or in the change of the version number of a drawing. A more intricate assessment of a drawing's semantics and the pragmatics of its use contexts, for example, what detail is needed now, is involved.

There was specialist terminology that was evidently linked to the knowledge work of these engineering design specialisms that changed the sense in which some everyday words were used. With a large data corpus, evolutionary learning of specific terminology is technically feasible; however, in this setting there was lexical, interpretative ambiguity with reference, at different times, to a "plant room," an "energy center," and an "ecocenter." These are terms that do not readily lend themselves to easy disambiguation (to "word"–"meaning" mapping). There were further consequences in the use of these terms, in the calculation floor areas, and this was a distinction it would have been helpful to be able to locate in the conversation. However, the meaning of these terms may not be universal across all design teams and "learning" may need to be local and organization or project specific.

Even within this brief conversational sequence, interpretative, lexical ambiguities were intertwined with missing information uncertainties, and the same term was not used consistently to refer to the same building element throughout. Some structures in speech are easier than others to locate and disambiguate in conversation. The structures of talk that featured in these analyses, including formulations such as assessments and (dis)agreements, are not so easily rule defined. Although no plan toward the design of support to locate missing information is given here, with advances in computational linguistics and evolutionary natural language processing expertise, this endeavor may be viable.

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