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A METHODOLOGY FOR COMPARING DESIGN PROCESSES

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Abstract

We gain insights into design processes by recognising similarities to other processes, often in radically different industries. The crucial determinants of what happens are characteristics shared with *some* other design processes. But there is no way to draw on comparisons beyond one's own experience. We are developing a programme of comparative design research that aims to map the similarities and differences between design processes, and develop a deeper understanding of how and why design is done differently in different industries, and how effective practices can be transferred between industries. In this paper we outline a methodology for creating analyses of design processes that facilitates both cross-process comparisons and the integration of different analytical perspectives on design. The analyst draws on a catalogue of previous design process descriptions for useful concepts, to map processes as a network of participants and activities and the relationships between them, and describe the causal relationships between the properties of the participants, activities and relationships.

Keywords: process modeling, types of design, research methodology, ethnography

1 Introduction

When studying engineering design processes, we have found that we get insights from radically different industries. We see things that are invisible to people who only know one industry. What look like very different design processes producing very different products turn out to be remarkably similar in some crucial ways. But how can we collect and systematise these insights to develop a richer understanding of designing? How can engineers wrestling with how to improve their processes gain an outside perspective on their problems?

In this paper we outline a programme for comparative design research that we are pursuing [1]. We put forward a methodology for analysing design processes as maps of participants and activities linked by relationships, with meta-level maps of causal connections between the characteristics of the participants and activities. The methodology is designed to be simple and flexible enough to be practically useful, while facilitating the development and practical use of cross-domain comparisons.

2 Comparative design process analysis

Explicit comparisons between different types of designing are thin on the ground [but see 2, 3]. Attempts to describe how designing is done (for real, in industry) have almost all fallen into one of two categories: One, theories of design that attempt to cover all design. As real-life designing is a diverse and complex multi-faceted phenomenon, such theories are very

abstract, and each one covers only a single aspect of designing. Two, descriptions of how designing is done or should be done in a particular industry, or even just a single episode of design. Two important strands of research on design processes consciously adopt a narrow focus: the German tradition of prescriptive solution-oriented research on design methodologies grounded in detailed case studies [e.g. 4]; and ethnographic observations of designers at work, drawing on the methodology and intellectual concerns of sociology [for instance 5, 6].

Our view is that, on their own, the universal and domain-specific approaches are both too limited. Many important aspects of designing are characteristics that particular design processes share with *some* others. Universal theories misunderstand or exclude these characteristics; while domain-specific accounts can conceal their significance by not describing them abstractly enough to reveal their generality. Likewise similarities to non-design activities such as scientific theory development are ignored or downplayed.

Our approach to understanding designing is empirical and data-driven, though informed by an analysis of similarity in design [see 7] and by philosophical analyses of scientific procedure [notably 8]. We compare a variety of aspects of design processes in different industries, identify similar and different features, and seek to explain the similarities – an incremental and piecemeal development of understanding. So far our comparative studies have depended on spotting potentially-general phenomena and looking to see if they turn up in other industries. For instance Claudia Eckert has found her understanding of knitwear design extremely useful in making sense of the interactions between engineers designing helicopters and diesel engines [9, see 10].

Our aim in proposing a programme and a methodology for comparative research is to develop effective ways to identify and describe similarities and differences between design processes, so that researchers and practising engineers can draw on comparative insights beyond their own experience – so that comparative research can be cumulative. This programme is methodologically open – our goal is to combine the insights and comparative analyses of researchers working in different disciplines, such as cognitive psychology, social psychology, sociology, organisation theory, cultural studies and so on, each with its own set of assumptions, data collection methods and analytical techniques. It only entails a commitment to a meta-methodology for describing results in a form that facilitates comparison and integration.

3 Patterns and chains of causal influences

When we make comparisons between design processes, we see that they have some features in common, while other features are different. Understanding lies in knowing *why* they share some features but not others. The first step is finding clusters of common features – recurring *patterns* of designing behaviour. (Note that our use of the word *pattern* is unrelated to Christopher Alexander's concept of design pattern [11], meaning an abstract solution to a type of problem, which has been widely adopted by software engineers [see 12].) The second step is explaining the patterns: figuring out whether the features are causally related, or are symptoms of the same underlying cause. A pattern only becomes significant and interesting when we have a persuasive causal story to explain how its elements are related. The third step is integrating each new pattern with its associated causal story into our existing body of understanding. Features can take part in different causal processes: these can amplify each other's effects or counterbalance them, or one causal process can block the operation of another.

The patterns we identify though comparisons can be at a variety of different levels, such as procedures for solving particular types of technical problems, or how individual designers act in certain social situations, or how factors such as the relationships with customers influence the collective behaviour of organisations. One aim of the comparative programme is to uncover the relationships between aspects of design that appear when processes are viewed from different perspectives at different scales.

Design processes inevitably comprise a dense network of causal influences. What the network looks like depends on one's perspective, and on how much one wishes to include in the analysis. If one looks for the consequences of a feature, they fan out like a tree from the root cause. If one wants to explain a particular phenomenon, one sees a chain, or a funnel of converging causal connections. If one looks at a system holistically, one sees a lattice of causal connections, most likely with loops.

In order to make comparisons between domains we need to view features of design processes at the right level of abstraction to see commonalities. The descriptions of features and causal connections we consider can have different levels of abstraction and thus cover broader or narrower ranges of design processes – it may be useful for us to consider more and less general conceptualisations of the same features. The challenge is to find the most abstract, and thus broadest, descriptions that both fit the experiences of engineers and researchers, and accurately characterise the sources of causal influence. Descriptions that are too abstruse to be comprehended easily and used are no use to us, nor are descriptions that exclude the details that actually determine why a process works the way it does.

4 A catalogue of patterns

In order to enable designers and researchers to take part in and make use of a cumulative programme of comparative studies of design, we need a way to organise and record the results generated by the programme. We are developing a catalogue of patterns and causal relationships, as well as the other elements of process descriptions that we find useful. All of these are classified hierarchically, to highlight the similarities and distinctions between phenomena observed in different case studies. The catalogue contains descriptions of the same observed phenomena at different levels of abstraction and generality. What forms of hierarchical classification – what abstraction gradients – are possible and useful is a question we are still investigating.

Researchers taking part in our cumulative programme of comparative design research – for scholarly purposes or trying to solve practical problems – search the catalogue for potentially useful concepts and for similar phenomena found in other processes, and employ them to make sense of the new process.

But the catalogue is always a work in progress. People using it should always critically assess how well existing categories and descriptions fit their own problems and examples. Very often they won't fit very well; then the analyst should define new elements of design processes, features and causal mechanisms, and add them to the catalogue. Wherever possible they should be inserted into existing hierarchies of concepts, and the descriptions of both new and old concepts should be adapted to make explicit the conceptual distinctions that the analysts think are necessary or useful. In our own less formal experience of making comparisons based on personal experience of other design processes, we find that potential points of similarity are useful prompts for critical thinking about what is happening.

5 A methodology for describing processes.

The approach to describing what is going on in design processes, the similarities and differences between them, in terms of patterns of features and causal explanations for them, is entirely separate from any method for finding them. We have no intention to restrict comparative design research to any methodology. However we are developing a methodology to apply in our own case studies, which investigate problems and processes at particular companies, and are informed by ethnographic practice even when not strictly ethnography.

5.1 Entity relationship diagrams to map processes

The methodology we describe here is the construction of a map of the parts of the process the analyst is interested in, by drawing on, critiquing and extending the sets of process elements identified in previous studies. This makes explicit the similarities and differences from other design processes by generalising and specialising the descriptions of the elements the analyst uses in the map. While the steps in the methodology have a logical order, they are inevitably interwoven; progress with task five, identifying causal connections, will often drive progress with the earlier tasks.

The first task is to identify the participants in the process. As well as individual designers and groups, the objects and information structures they work with play roles in the process. Descriptions and models of the designed artefacts themselves, requirements specification documents, tools such as CAD systems, and so on, exert an influence on what happens. (We discuss the question of what the participants in processes can be in section 8)

The second task is identifying the activities in the part of the design process the analyst is interested in. This may involve selecting activities – consciously deciding to limit the inquiry to certain aspects of the process – and dissecting them into a hierarchy of components and considering both larger-scale activities and their components simultaneously. Sometimes we may want to consider designers' individual actions and events; for the types of analysis we describe in this paper we can regard these as being very small-scale activities.

The third task is the much more difficult and uncertain process of identifying the relationships between participants and activities in the process. These include relationships between participants and participants, and between activities and activities – we think it is unhelpful for our purposes to insist that relationships between activities are actor-specific, or that relationships between the participants are activity-specific. The network of participants and activities and the relationships between them form a map of the part (or aspect) of the design process in which the analyst is interested.

Here it's essential to remember that interactions between people, things and activities can have more than two participants, so one can't just treat relationships as binary connections. While activities are conceptually very different from their human and non-human participants, they play the same role in the map of the design process. They are 'things' connected to each other through relationships, while the relationships are only connected to each other through participants and activities. Thus the map is what mathematicians call a *bigraph*. Two participants or activities in a process may be linked through more than one distinct relationship.

Modelling systems as entities and relationships is a familiar activity in the field of software engineering, which has conventions for drawing entity relationship diagrams (notably within UML) that are useful for including superclass-subclass relationships and aggregation relationships within diagrams showing the associations between different entities. Our

approach to describing design processes differs from conventional ER modelling in one important way. We always treat the relationships between participants and activities in design processes as nodes in the graph that have properties of their own (entities in ER modelling terminology); software designers include entities in ER diagrams to represent intangibles such as associations only where necessary or useful. In our process maps, links labelled only with the role each entity plays for the other (which are relationships in ER modelling terminology) exist only between relationships and participants or activities.

5.2 Characteristics of entities are the units of analysis

The participants in a design process, the activities they engage in, and the relationships between them have *characteristics*. Some of these characteristics are binary – present or absent – while others are matters of degree – parameters with values. The fourth task (logically, if not chronologically) is identifying significant characteristics of the participants and relationships in the map of a design process.

These characteristics are the units of our analyses of causal mechanisms influencing design processes. The causal influences we aim to identify are characteristics themselves, and typically result in other characteristics (of the same or other participants or relationships) being present or absent or greater or lesser. However the causal influences of some characteristics can cause entire relationships to exist or not exist, or some participants to be included or not.

5.3 Causal connections as meta-level maps

The fifth task is to understand and describe the causal connections between the characteristics of participants in the design process and the relationships between the participants. As causal influences on what happens in a design process vary in strength, and can be counteracted or blocked by other causal mechanisms, these causal connections will typically be described as causal pressures rather than rigid determining factors. These descriptions of causal connections constitute a separate meta-level map of what is going on in the design process, on top of the primary map of participants and their relationships.

In our approach, identifying characteristics and analysing the causal relationships between them is the core of comparative design process analysis. However we don't aim to prescribe a methodology for it. Analysts trained in different disciplines, such as cognitive psychology or sociology or organisation theory, will apply the data gathering methods and analytical techniques of their disciplines to the aspects of design that interest them.

We find that we often describe the causal connections between the characteristics of entities as chains of features of the design process [9]. We often naturally describe these intermediate features in terms rather different from characteristics of participants, activities and relationships. Two questions arise. First, can such feature descriptions always, with a little thought, be translated into characteristics of participants, activities or relationships? We currently think the answer is yes, whether this is always easy in practice is an open question. Second, when is it worthwhile to perform the translation? This question we also want to leave open. Translating such causal features into characteristics of entities and relationships serves as a driver for developing more sophisticated and informative maps of design processes. However the effort-to-insight ratio will vary for particular studies.

5.4 The big picture: relating process maps to other analyses

The engine for making comparisons between design processes beyond an individual analyst's own experience is the catalogue of design process elements. This catalogue records

participants, activities, relationships, characteristics, patterns of features of design processes, and causal connections. The analyst searches the catalogue for descriptions of participants, activities, relationships and causal connections that are similar to what the analyst observes. These provide a starting point for describing the new process as well as a prod for critical thinking and a source of hypotheses. At the same time the analyst critically evaluates the concept descriptions and the elements of provisional local theory they embody, and revises the catalogue to include descriptions of participants, activities, relationships, characteristics and causal connections that accurately cover the new process.

Whenever someone analysing a new design process can make effective use of the concepts used to describe another process, comparative questions arise. How similar are the two (or several) processes, and in which ways? How general are the phenomena that the catalogue elements describe? How abstract do we have to make our descriptions to get them to fit all our cases? Do these abstract descriptions capture the causal factors that influence design processes, or have the crucial causal factors been thrown away with the details?

6 Example of a Pattern

A recent case study by the authors involved an analysis of the communication behaviour in a consultancy division of a large corporation in the process of changing from internal to external funding. The situation was very tense and the employees were dissatisfied with their communication and generally unhappy. We had to make sense of a situation that did not conform to our expectations of a small co-located organisation where people take obvious pride in their own expertise and that of their colleagues, characteristics which promote good communication (Figure1). We had to understand this situation by finding causal explanations.

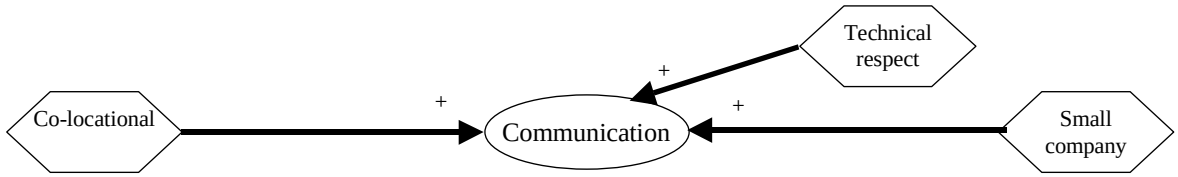

Figure 1. Small co-located organisation pattern

While only comprising 40 employees the organisation had five layers of hierarchy largely to shield senior managers, who did not enjoy people management, from the day to day operation of the organisation. In addition individuals did not like each other, partly due to management favouritism. This had disastrous consequences for communication.

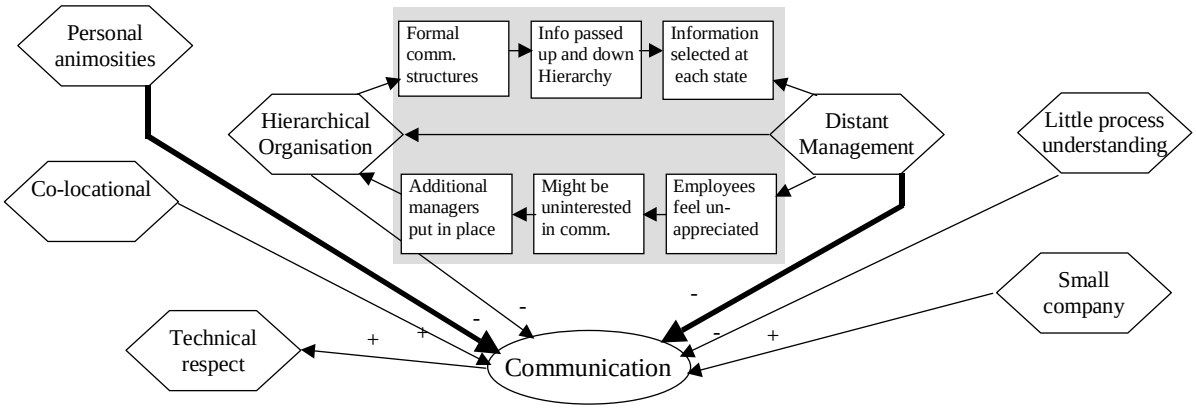

Figure 2. Distant Management and Personal Animosity Pattern

Many organisations have elements of personal animosity and management shortcomings influencing communication. However in this case these factors exerted a strong and salient causal influence on the behaviour of the organisation, therefore constituting a significant pattern. In later case studies we have begun to look for this combination of factors, to discount or include them in other analysis of communication behaviour.

7 Activities are fluid, characteristics are fractal, maps are provisional

For any analyst, describing the relationships between participants and activities and identifying and labelling characteristics will seldom be straightforward. This is partly because what activities to include, and what aspects of participants and relationships are important enough to focus on, is a pragmatic choice. Whether to treat a complex interaction between a pair of participants in a design process as one relationship or two or several may not be obvious. Many activities in design processes, especially those done collaboratively, do not have clear boundaries; what to include within an activity description, and whether to split an activity into its components, may be difficult questions. This issue is made more complex by the participants in work practices such as designing often pursuing different agendas simultaneously and with the same actions [see for instance 13].

Similarly, characteristics are fractal: naming the characteristics of participants in design processes and the relationships between them will often be giving labels to the emergent consequences of complex interactions or aggregations of disparate elements. Such characteristics could and sometimes should be decomposed to reveal the finer-grained structure of the interaction between the participants in the design processes. But attempting to be exhaustive in unpacking these complexities will result in voluminous, fine-grained, and immensely effort-intensive accounts of local, small-scale designing behaviour – witness ethnomethodologists' elaborate and sophisticated analyses of seemingly simple and mundane social behaviour such as queuing in shops [14]. Investigating the subtleties of the microstructure of local episodes of design behaviour is an important part of design research, which can certainly be integrated into our approach. But we are also concerned with understanding coarser regularities in larger-scale phenomena, which entails accepting activities, relationships and characteristics as useful units of analysis when we know that they are conceptually problematic.

The consequence of this is that maps of design processes in terms of participants and activities and their relationships, their characteristics, and the causal influences that govern them, are necessarily incomplete and provisional. Nevertheless finding good conceptual distinctions that reveal causal mechanisms and similarities and differences from other processes is crucial to discovering patterns of designing.

8 Philosophical issues in design process mapping

The approach to comparative design process analysis we outline here skates over a number of complex philosophical issues. We aim to sidestep them rather than solve them, for three reasons. The first is that we are centrally concerned with understanding emergent properties of design processes that are difficult to characterise in philosophically or methodologically rigorous terms. The second is that we want our methodology to be easy and straightforward to use, so that people who are not philosophers or social scientists will use it to address practical

problems. The third is that we want to include researchers with different concerns and philosophical suppositions within our programme, to contrast and integrate their views.

The causal stories linking the properties of participants, activities and their relationships constitute elements of a fragmentary and local theory of designing. Hypothetico-deductive method is central – conjecturing hypotheses about what relationships and causal influences link the participants and activities in the process, and actively seeking evidence to test them. This is of course entirely compatible with an ethnographic approach to carrying out case studies [15].

In this approach to analysing design processes, we are crucially concerned with philosophically tricky issues of ontology – what fundamental kinds of things exist, and what is their nature – and taxonomy – within each kind of thing, what different types exist and what is the structure of that variation. But we propose to deal with these issues by letting people who are looking at real examples suggest and negotiate the categories that make sense to them.

One such question is what we should accept as a participant in a design process, besides individual humans. The proponents of Actor-Network Theory argue that inanimate objects are agents in social processes as much as people [for instance 16]. While we don't fully subscribe to their position, we think that recognising the roles of objects in processes is crucial [see 6]. Interpretivist approaches to studying work cultures including Soft Systems Methodology [17] reject the idea of social structures such as divisions into functional areas or project teams as having objective existence. While they have a valid point about how people construct their understanding of their social environments, we think that our purposes require us to treat groups and organisational structures as things that cause and are caused by other features of design processes. However we should be wary of taking our informants' accounts of how they work at face value. Similarly, the interpretivist camp rejects Popper's contention [19] that knowledge has objective existence independently of someone knowing it and distinct from particular physical objects recording information; but treating information structures s8ch as requirements as things can be a useful pragmatic step.

Treating activities as things is still more problematic. Not only is any named activity both an aggregation and an abstraction of many smaller-scale activities, but individual people construct different subjective views of what activities they are involved in through their interactions with their environment [see 17]. So we should be careful about taking any account as true, or better than another participant's viewpoint. Nevertheless, observers and participants in design processes are able to point to and agree about activities that they think of as entities and that serve to structure what they do and think about. It is very difficult to characterise either designers' actions, or phenomena that are the emergent consequences of intricate combinations of actions, without treating activities as entities.

We allow analysts to use the ontologically-vague notion of causal feature in describing causal influences. This is a shortcut that obscures the structure of design processes that is revealed by using the element categories discussed here for the sake of using the descriptive terms analysts and their informants find natural for conceptually messy phenomena. Our current view is that this is acceptable as long as analysts are aware of the conceptual shortcuts they are taking. However some researchers with particular philosophical and methodological positions may want to take a more carefully considered and philosophically rigorous position on what the actors and features of design processes are, and we do not wish to exclude them from the comparative project.

Social scientists have extensively debated not only what concepts it is legitimate to use in analysing social phenomena such as design processes, but also the epistemological status of

their analyses. Whether or not any of our case studies qualifies as ethnography, we accept the view of the ethnographers, that the maps and causal explanations of the features of design processes produced by the methodology outlined here are *interpretations* of the processes [see 15]. These interpretations are not unique – another interpretation of the same process employing very different conceptual terms could be equally valid. For ethnographers the test of the validity of their analyses of a culture is that they should ring true for the members of the culture itself, even if they don't normally think in the terms in which the analyses are formulated [15]. In the incremental revision of provisional explanations, a robust "No, we don't do it like that here" is as useful as a "Yes, you're right".

9 Comparative insights into design processes

We believe that it is sometimes possible for engineering companies to identify ways in which other companies, perhaps in radically different industries, have better solutions to similar problems, and import good practice. One aim of our comparative programme is to facilitate finding potential sources of good practice and to provide practising engineers and other designers with a toolkit of concepts and comparisons with which to reflect more critically about how their own design processes work. This critical reflection can alert them to the possibility of problems they had never imagined, or suggest that known problems may have causes they had not considered. This can work in two ways. First, designers can draw on individual case studies, maybe described informally in anecdotes, for which the general labels in the pattern catalogue provide an index [9]. Such informal anecdotes can serve as a filter to pick out the most relevant parts of the catalogue of previous design analyses for more detailed consideration. Second, designers can use the methodology described here to analyse their own processes from unfamiliar perspectives. One of the strengths of our approach is that it enables the explicit combination of different perspectives on what happens in processes. As with many formalisms and analytical methods, the increased understanding that results from thinking hard with a new set of ideas is likely to be more valuable than the documented end product.

However we are also concerned with developing an integrated understanding of design processes as multi-layered multi-faceted activities. Our programme of comparative design analysis is intended to achieve this by accumulating and revising bits of local partial theory, the patterns of recurring characteristics and their causal connections, using the techniques and conceptual terms of several different disciplines [1].

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