The Logic of Practices of Stigmergy: Representational Artifacts in Architectural Design

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ABSTRACT

In their cooperative design practices, architects form series of interwoven representational artifacts. On the basis of a field study of architectural design, this article presents an analysis of these practices and shows how they are partly coordinated directly through the material field of work. This is described as ‘practices of stigmergy’. Furthermore, the article considers the practical logic and the economy of second order effort in such practices. In doing so, it outlines an approach to the investigation and conception of such practices of stigmergy.

Author Keywords

Material artifacts, coordination, stigmergy, cooperative work, architectural design.

ACM Classification Keywords

K.4.3 [Organizational Impacts]: Computer-supported collaborative work

INTRODUCTION

In this article an attempt is made to achieve a better understanding of how collaborative work in a building project is accomplished by actors through the creation, combination and merging of representational artifacts. Whereas a number of previous studies have focused on single artifacts (e.g.[13, 19]), this study seeks to explore how artifacts are permutated and form series of interwoven artifacts in support of actors when accomplishing various segments of a collaborative work effort (a focus shared with e.g. [20]). What is implied here is an understanding that every representation takes its form from its position in an ensemble of tasks, performed in series or in parallel and usually, in the context of architectural design and planning, in a collaborative work effort. We shall return to a discussion of this below.

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The arguments are based on an ethnographic study tracking the creation, combination and merging of representations relating to the design of a building and the planning of its construction. The physical location observed is an architectural office. This is arguably an excellent location for the study of collaborative work practices, based on representational artifacts. Drawings, plans and descriptions of buildings are continuously created, read, calculated, approved, disapproved, transformed, altered, specified, annotated and formatted by the cooperative work ensemble as required in the design process. One of the characteristics of work on building projects is the effort to achieve continuity and integration with regard to the collaborative work carried out by a large and diverse ensemble of actors. These efforts are supported by the creation, combination and merging of representations, i.e. by what is described below as practices of stigmergy.

The aim is to approach an understanding of the logic and economy of such practices. It is hoped that this will further an understanding of representational artifacts as a basis not only for the accomplishment of architectural work, but also for the coordination of this distributed process. This may prove to have certain implications for the general conception of the coordination of cooperative work through artifacts.

We will proceed in the following manner. First, we will attempt to show that every representation takes its form from its position in an ensemble of tasks, performed in series or in parallel, and usually by many people working together on the design and planning of the building project in question. Secondly, we will discuss how this is achieved through what could be described as practices of stigmergy. Thirdly, the economy of second order effort in practices of stigmergy will be considered. Fourthly, the logic of practices of stigmergy will be discussed. Finally, an outline will be drawn of some of the implications for the field of Computer Supported Cooperative Work (CSCW).

METHODS

The paper is based on fieldwork carried out in the course of fourteen months in an architectural office and on a construction site. In this period, work within the domains of design and planning in relation to several building projects was studied. One of the building projects, the development of the new domicile for a publishing house, was a multi-storey building in glass, steel and concrete (see Figure 1) constructed at the city of Copenhagen's waterfront. A combination of observation and interviews was used. The fieldwork also included collecting (scanning, taking screenshots or photographs of) artifacts used and produced by the actors engaged in the building project.

THE BUILDING PROCESS

In this section we will be concerned with the design of a building. Initially, we will place these interrelated practices within the larger context of the building process in order to give an impression of the complexities involved. Subsequently, we will turn to design in greater detail.

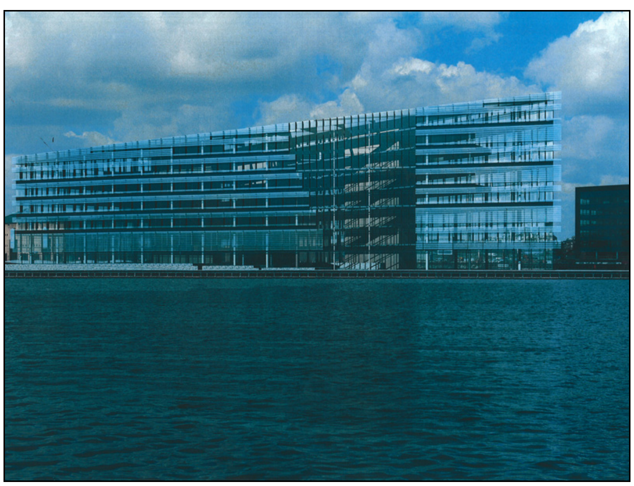

Figure 1: Representation of the projected building made for presentation purposes

The building project begins with the client as such projects almost always do. In this case, the client is a publishing house in need of a new domicile. In order to develop the project idea and move on to the completion and use of the building, the project has to be planned and worked out step by step, phase by phase, in increasingly complex detail. The original abstract idea is gradually fully formulated by the architects, concretized and implemented in stages. Gradually the project takes shape, requirements are put down on paper as written text and the first sketches are drawn up. The number of people involved increases, sketches become scale drawings, and drawings become the basis for applications to the authorities. After permissions have been issued, tenders are invited from contractors, and commission is awarded to a general contractor. The general contractor then hires the various trades and the aim of putting up the building is within reach once the working drawings have been made and the trades has been coordinated on the building site. This process could perhaps be described as a series of interwoven tasks.

Ingold [12], coins the concept of taskscape:

'How, then, should we describe the practices of work in its particulars? For this purpose I shall adopt the term 'task', defined by any practical operation, carried out by a skilled agent in an environment, as part of his or her normal business of life […] Every task takes its meaning from its position in an ensemble of tasks, performed in series or in parallel, and usually by many people working together […] It is to the entire ensemble of tasks, in their mutual interlocking, that I refer by the concept of *taskscape*.' [12, p.195. Ingold's italics.]

Following Ingold, we could describe the building process in terms of a taskscape. A taskscape consisting, as Ingold puts it above, of 'an ensemble of tasks, performed in series or in parallel, and usually by many people working together'. Here, the ensemble of task could be described tentatively as comprising sketching the design concept, obtaining a building permit, creating the tendering project, awarding the contract to a general contractor, drawing up working plans, designing building services, scheduling the construction work, and performing the actual construction. As mentioned above, in the following we will mainly focus on the design.

Design in architectural work

The task of designing a building has emerged and evolved over the past centuries as a discipline mainly carried out by architects and engineers. Building design provides representations of the building in the form of schematics and drawings that are used not least by the contractors and builders doing the actual construction work [27]. According to Schmidt & Wagner, in order to understand the significance of representational artifacts in architectural work, one must take into account that architectural work is different from many other types of work insofar as the 'field of work' does not exist, that is, does not exist objectively, in advance, but is constructed in and through the process of design and planning [20, p.16]. The design of a building is subdivided into phases of conceptual design, tendering project, and working plans (these stages are partly legally, i.e. contractually, defined). In the following we will outline how these stages are accomplished through artifacts.

Conceptual design

The conceptual design takes place at the very beginning of the building project in the office space of an architectural firm. The initial development of the design concept is mainly concerned with the exploration of geometry, volume and materials as well as the flow of people within and around the projected building.

Using various types of representational artifacts, the architects explore and develop the building's design. Loose sketches are used by the architects to explore the geometry of the building, in this case a triangular shape with an atrium drawing light into the centre (see Figure 2). Other sketches represent the flow of people and things, through entryways such as doors, stairs and elevators rendered with patterns of loose lines. In addition, colour samples assembled on a piece of paper set the 'maritime' colour scheme of the building (in line with its placement at the waterfront). Finally several models are crafted in wood or cut in foam in order to visualize the design concept three-dimensionally.

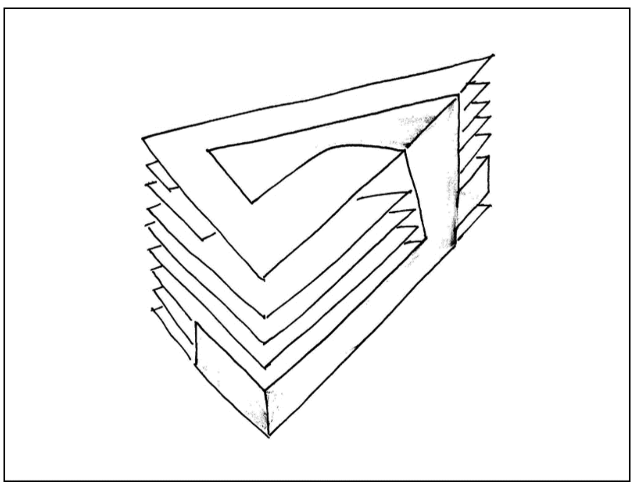

Figure 2: Sketch of geometry.

If something general could be said about the representations of the building created at this stage, it could be that the detail level of the representations is relative low - compared to the representations we find in more advanced stages of the building project. This could be explained by the fact that these sketches and models are made in a process of exploration with the purpose of inviting further exploration. At this juncture, that is, the representations are made for the benefit of the architects' own design process and not in direct support of, for example, the builders' construction effort (representations meant to serve the actual construction of the building are called 'working plans' and these are made at a more advanced stage of the building process). Furthermore, the scope of the collection of representations made at his point only includes broad design features (i.e. main geometry, volume, materials, colour, flow etc.); numerous details still need to be worked out as the conceptual design stage draws to a close.

Tendering project

Parallel to and exceeding the conceptual design work is the creation of 'the tendering project'. Once the client and architects feel confident in the design, a contractor able and willing to construct the building must be found. This process is called tendering.

All the documents needed to give a comprehensive view of the project must be provided to all the potential general contractors as part of an invitation to tender. This invitation takes the form of descriptions and drawings, and the bid for the building contract is made on the basis of this invitation. It must convey the overall complexity and size of the project, its build quality, the construction principles asked for, the time frame set for the construction and so on. This is done in order to give the potential contractor a fair impression of what they are asked to build.

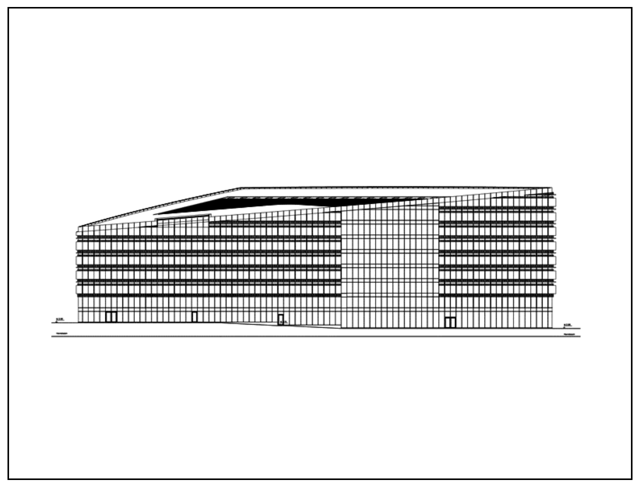

Figure 3: CAD drawing made for tendering purposes.

As mentioned above, architects sketch an outline of the building using various types of representational artifacts. Now this outline has to be elaborated and drawn to scale for tendering purposes. As we shall consider below, based on the collection of sketches, the building constructors transpose and elaborate the sketched outline of the geometry of the building into a three-dimensional CAD model with a limited number of details.

Hand-drawn sketches are transposed with a technique referred to as 'computer aided design' (CAD). In practice, this involves a division of labour in which the architect's hand drawn sketches made with pencil and paper are reproduced in a CAD application by a construction engineer. The hand-made sketches are transposed and made to scale in three dimensions (e.g. 1:200) with straight lines and perfect geometry. This is a matter of the construction engineer placing the sketch next to his CAD workstation and referring to it as he develops the CAD rendering of the building's geometry.

In this manner the CAD model is created with a limited number of details covering the main proportions of the building's geometry (full detailing and their measures are not given until the creation of 'working plans' – we shall return to this below). An overall sense of proportion is given in the hand drawn sketches; however, the systematic interrelations of the exact measures must be computed by the construction engineer in this first fixing of the building design in a CAD model. This is possible without any explicit communication with the architect in regard to this subject, because the height of a room, the width of a door and the size of a window, for example, has standard dimensions, and the architect's sketches suggests the overall proportions.

Compared to the representations we considered in relation to the conceptual design, at this stage, the detail level of the representations is higher and the scope of the representations considered as a whole is broader (i.e. it includes more of the projected building). This could be explained by the fact that these CAD models are created with the purpose of conveying an impression of the building sufficient in scope and detail to serve as a basis for contractual negotiations for the building contract. That is, the representations at this juncture are not made for the benefit of the architects' own design process; it is made in direct support of the tendering process. This does not entail, however, that the representations considered as a whole are fully detailed and of full scope. In the words of an architect, 'the tendering project is made on a need to know basis. We know that much of it is going to be revised later on anyway, so there is no point in making too much of it'.

From the three-dimensional CAD model a number of two-dimensional drawings are generated. That is, the architect or building engineer working with the CAD model selects a number of views of the building (elevation view, section view, plan view, etc.) and exports them from the CAD application as two-dimensional drawings (often in PDF format). These drawings are printed out and attached to the invitation to tender. They include: a land registry plan showing the position of the building in relation to the surroundings, a location plan showing the position on the lot, plan views showing the building in the horizontal plane, elevation views in the vertical plane showing the building from the outside, section views in the vertical plane cutting through the building, detail views showing principles of montage, and plans showing the proposed interior decoration, etc. In these representations, dimensioning is restricted to rough measurements. In plan views, for example, external dimensions and important room dimensions are stated in order to make room sizes and overall measurements comprehensible. Individual doors and windows, for example, are not dimensioned.

The tendering project consists of a total of fifty-four CAD drawings and a ninety-six pages of written description - in comparison, the collection of working plans generated from a much more elaborated model, that we are about to turn to, numbers some two thousand CAD drawings and several thousand pages of written descriptions.

Working plans

Only after the negotiations for the general building contract has been resolved and a general contractor has been found, does the creation of the working plans begin to gain momentum. The creation of working plans takes place throughout the construction of the building. That is, the creation of a particular working plan is only ahead of the construction of a section of the building by a few weeks or so, sometimes even less.

The architects and building constructors base the creation of the working plans on a direct elaboration of the three-dimensional CAD model that was initiated in the tendering stage. The model made in the tendering project is of a limited detail level, as mentioned above; the detail level is vastly increased as workings plans for every section of the building is created. Perhaps it would be timely to take a look a how this process of design with CAD models unfolds.

The basic units in any CAD model of a building are referred to as a 'building objects'. Building objects commonly used are representations of doors, windows, ceiling, staircase etc. A building object such as a wall, for example, contains geometry as well as specifications of its attributes. In most cases these building objects are predefined in the database of the CAD application, serving as a resource for the architect or construction engineer. The construction engineer, for example, creates the construction model by combining and manipulating a number of building objects - he or she could for example combine floor objects with ceiling objects and wall objects. At a later date, the same or perhaps another actor could add window objects and door objects to the model in a manner consistent with the placement of the previously placed building objects. That is to say, the individual actor creates part of a CAD model by combining a number of conventional predefined building objects. In turn the same or perhaps another actor notices this and ads further building objects to the CAD model. In this manner work on the CAD model unfolds and is elaborated.

Bearing in mind that the working plans are to be used for the accurate construction of the building, the engineers and architects at this juncture aim to represent the geometry of the building in its entirety and provide all the dimensions of the specific building elements that are involved in the construction process. This is most often simply a matter of the construction engineer or architect loading the relevant CAD file into his CAD application and picking up where he himself or others left off in the tendering stage. The working plans must include what is already shown in the tendering project, and in addition the height, width and depth of every specific building element provided.

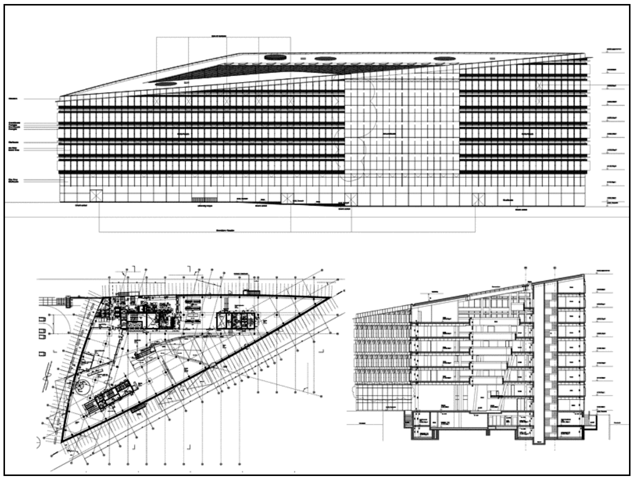

Figure 4: Collage of working plans.

From the elaborated three-dimensional CAD model a large number of two-dimensional drawings are generated for the purpose of conveying to the contractor and builders precisely how every aspect of the building should be constructed. That is, based on the elaborated model the building constructors turn out a large collection of highly detailed CAD drawings of an almost all-encompassing scope and these are put into the hands of the men and women doing the actual construction work. In principle, every detail should be accounted for; in practice, however, that it not the case. It is assumed that the builders have the necessary skill and experience to fill in some blanks themselves (we shall return to this below).

Recall how the working plans are based on the representations made in the tendering stage, much as these has inherited content from the sketches made in the design stage. That is, representational artifacts inherit content from one another in a sequential manner throughout the process. What is the nature, logic and economy of these practices? We shall attempt to explore this question below.

PRACTICES OF STIGMERGY

The various actors distributed across the taskscape continue the work on representations created previously by other actors or themselves. In the following we will describe this phenomenon as practices of stigmergy. We will consider, in turn, the economy of second order effort in practices of stigmergy and the logic of practices of stigmergy.

According to Christensen [2], drawing on Grassé [6], the notion of practices of stigmergy amounts to the following: in addition to relying on second order coordinative efforts (at meetings, over the phone, in emails, in schedules, etc.), *actors coordinate and integrate their cooperative efforts by acting directly on the physical traces of work previously accomplished by themselves or others* [2, p.17]. Perhaps it would be prudent to elaborate on this.

The notion of stigmergy, coined by Grassé [6], entails that a coordinative effect can occur when individuals act on the physical traces of work accomplished previously by themselves or others - a notion that could perhaps be applied to the context of architectural work and planning.

Recall how the construction engineers created the working plans through projections of and elaborations on the tendering project, and how the tendering project was made by the construction engineer transposing the architect's design sketches. In more abstract terms we could say that actors coordinate and integrate their cooperative efforts by acting directly on the physical traces of work previously accomplished by themselves or others and that signs left or modifications made by individuals on artifacts may, given an appropriate context of practice, become meaningful to these individuals themselves or to others and in turn inspire new actions on artifacts. This is what we suggest to describe as practices of stigmergy in architectural work and planning. In this manner coordination of collaborative work is achieved without necessarily resorting to articulation work.

Articulating the interdependences in cooperative work through second order efforts is conceptualized as articulation work by Strauss [24, p.8]. Recall that in a standard large building project various actors work on different sections of the building and they may be responsible for particular design tasks. In addition to the architects and building engineers, a building project involves many external actors: technical specialists for construction, electricity, heating and ventilation etc. Furthermore, several other actors are involved, including a client and perhaps one or several users, several authorities, building companies, subcontractors, and a general contractor. Integrating these many professional competencies and their perspectives, mobilizing their support, is a major task that requires careful planning and ongoing communication. These interdependences are partly addressed at meetings. Scheduled meetings in which all project members take part are held at regular intervals; here they evaluate the progress of work, fix dates, settle responsibilities, redistribute tasks (if necessary), and discuss common issues such as design changes. At other times the interdependences are articulated over the telephone, by email and so on [20, p.355]. These efforts are made in an attempt to discuss the 'big picture', the overall progress of the design project, who does what when etc. Following Strauss [24], this amounts to what could be conceptualized as articulation work.

At this juncture we could note that the concepts of articulation work and stigmergy complement each other in relation to the analysis of coordinative practices in cooperative work in the sense that the respective concepts are not interchangeable, but address the conceptualization of very different empirical phenomena. Stigmergy, then, does not entail what could be considered extra or meta-work aimed at the coordination, as is the case with articulation work. In this view, we are stressing that in practices of stigmergy coordinative effects are achieved when actors act directly on the physical traces of work accomplished previously by themselves or others, rather than by way of second order efforts that assume a meta relation to the cooperative work effort and the interdependences involved (we shall return to this below).

However, before we can proceed with our reflections on practices of stigmergy in architectural work and planning we have to take into account that the concept of stigmergy as developed by Grassé [6], was not developed to analyse human practice, rather it was created for the benefit of the field of entomology. In order to avoid any unintended equations of human practice and insect behavior we have to consider what it involves to employ this concept in an analysis of cooperative work practices performed by human actors. As mentioned above, the concept of stigmergy was not developed in order to describe human practice [6]. Grassé developed the concept during his study of termite behavior [26, p.97]. When looking at a group of termites, they all seem to cooperate in building nests etc., but when looking at single individuals they seem to be working as if they were alone and not involved in any collective behavior. This appeared to be a paradox until Grassé introduced the concept of stigmergy. Grassé showed that the regulation of building activities among social insects does not depend so much on the workers themselves as on the material nest structure. A stimulating configuration of nest material triggers a specific building action of a termite worker, transforming the configuration into another configuration that may in turn trigger another (possibly different) action performed by the same termite or any other worker in the colony [6]. Thus, work in the termite colony is partly coordinated by virtue of the individual termites acting on the physical traces of work accomplished previously by themselves or others.

Perhaps, at this particular juncture, it would be prudent to briefly interject, without venturing into a literature survey, that although Grassé developed the concept of stigmergy during his study of termites, it has since been applied to other research fields. Initially to the study of other groups of social insects [30] not least the study of ants [11]. In addition, over the last decade or so, the concept of stigmergy has been introduced to the field of telecommunication especially in connection with the development of algorithms for network traffic, these algorithms are sometimes termed 'ant algorithms' [28], to the field of robotics [3], and to research concerned with multi-agent computer systems [7]. Recently, the concept has also been applied to sociological studies of online activity and learning [29].

Grassé used a stimuli-response model of action characteristic of the field of entomology in his work. We must be careful not to transpose this model of action to the context of complex human work practice. The field of CSCW is obviously dealing with human work practice and not the activities of insects, so we have to leave Grassé's stimuli-response model of action behind. In the context of human work practice and in relation to the concept of stigmergy perhaps we could ask ourselves: How do the actors identify the relevant 'physical traces of work previously accomplished' that are acted on in practices of stigmergy? Goodwin's [5] notion of *professional vision* could perhaps be helpful in relation to this question. We shall suggest that it is the professional vision or skilled vision of the actors that underpin practices of stigmergy and not stimuli-response. Accounting for professional vision could serve to sever the bond to any remaining stimuli-response model of action with regard to the concept of stigmergy. In addition, it may shed some light on how the design process, described above, unfolds through practices of stigmergy.

According to Goodwin [5], it is crucial to a number of professions that members are able to comprehend material artifacts specific to the web of professional practices that constitute a profession. That is, the practices clustered around the production, distribution and comprehension of such representations provide parts of the material infrastructure that partly makes up a profession [5, p.626]. Following Goodwin, we could suggest that within such a framework the ability to see relevant entities, for example, to see what in architectural work constitutes relevant 'physical traces of work previously accomplished' and act on them to a coordinative effect is not lodged in the individual mind, but instead within a community of competent actors. This notion has consequences.

First, professional vision in architectural work is not a purely mental process, but rather something that is partly accomplished through the material setting of architectural work practice. The practices investigated in this paper move beyond the mind of the actors to encompass material features of the setting, such as sketches and drawings where action is occurring.

Secondly, in so far as professional vision is lodged within specific professions (or clusters of related professions), they have to be learned [5, p.627] and architects and building engineers are in fact educated as such through formal education and on the job training. This does not necessarily mean that the actors in architectural work make great efforts to make sense of representational artifacts. According to Bourdieu [1] practice can involve a fair amount of unreflective routine and repetition. Most of the time, making sense requires no effort for the skilled actor, but for the novice this can be a different matter. What is meaningful from the viewpoint of the individual actor is closely connected to the training and skill of the actor, and his or her knowledge of and experience with the work setting.

We could suggest that practices of stigmergy are based on the actor's professional vision directed at the material field of work (e.g. sketches and drawings) where traces of work previously accomplished are recognized and acted on to a coordinative effect. Furthermore, professional vision is an acquired skill and by extension so are practices of stigmergy in the sense that they are based on the former. We could suggest that the stimuli-response model of action has no relevance here.

In sum, we have suggested that the concept of stigmergy, based on a notion of professional vision, could be fruitfully applied to the analysis of the integration and coordination of architectural work. The notion of practices of stigmergy amounts to the following: actors (partly) integrate and coordinate their cooperative efforts by acting directly on the physical traces of work, found on representational artifacts, previously accomplished by themselves or others.

The economy of second order effort in practices of stigmergy

As briefly outlined above, in practices of stigmergy no extra effort is made solely to coordinate and yet the cooperative effort is aligned and integrated. Perhaps we could suggest that practices of stigmergy is coordination 'free' of second order effort. As it stands, this is likely to be too compressed a formulation to be illuminating. To clarify we need, at least briefly, to compare the level of second order effort involved across the repertoire of coordinative practices in cooperative work. That is, in order to proceed we shall attempt to outline the economy of second order effort in articulation work including mutual awareness, and compare this to practices of stigmergy. In order to do so we shall turn to the literature and to the case described above.

As mentioned above in passing, the concept of articulation work was developed by Strauss, Gerson, Star, Schmidt, Bannon and others [4, 14, 18, 23-25], in order to account for, in the words of Strauss [24, p.8]; 'a kind of supra-type of work in any division of labour' performed by the cooperative work ensemble in order to articulate (allocate, coordinate, integrate, interrelate, mesh, etc.) their mutually interdependent individual activities in cooperative work. In cooperative work settings characterised by a dynamic work arrangement and involving a large varying number of participants, articulation work may become extremely complex and demanding [18, p.13].

Articulation work in an architectural office is conducted over the telephone, in hallways, at scheduled meetings, or in the form of email exchanges, it employs numerous artifacts including time schedules, meeting memos and other coordinative artifacts [20], and is carried out in what could be tentatively described as several interdependent dimensions: (a) Articulation in relation to actors, e.g. what architects and building engineers are available for a particular building design project. (b) Articulation in relation to responsibilities, e.g. who are accountable for what parts of the building design. (c) Articulation in relation to tasks, e.g. in what order are the design tasks to be carried out. (d) Articulation in relation to activities, e.g. what is the status of the buildings design. (e) Articulation in relation to conceptual structures, e.g. how to classify and archive the drawings. (f) Articulation in terms of resources, e.g. how much time is there to design the building etc.

This calibre of articulation work is complex and demanding, and in terms of second order effort perhaps it could be described as relatively 'expensive'. However, not all articulation work is 'expensive'. According to Schmidt [16, p.3] and Simone & Bandini [22, p.499], mutual awareness is the 'inexpensive' or 'cheap' mode of articulation work, however, it is *not* coordination without second order effort. In order to elaborate on this, we shall turn Heath & Luff's seminal study of mutual awareness in a London Underground control room [10].

To be aware of what your colleagues are doing and make them aware of what you are doing for coordinative purposes is to develop mutual awareness. Heath & Luff describes how the operators in a control room coordinate train traffic and movement of passengers on a particular line. The control room can house several staff, including the Line Controller who coordinates the day-to-day running of the railway and the Divisional Information Assistant (DIA) who, amongst other things, provides information to passengers and to Station Managers [10]. In this setting mutual awareness is produced through very delicate practices:

"On occasions, it may be necessary for the Controller to draw the DIA's attention to particular events or activities, even as they emerge within the management of a certain task or problem. For example, as he is speaking to an operator or signalman, the Controller may laugh or produce an exclamation and thereby encourage the DIA to monitor the call more carefully. Or, as he turns to his timetable or glances at the fixed line diagram, the Controller will swear, feign momentary illness or even sing a couple of bars of a song to draw the DIA's attention to an emergent problem within the operation of the service. The various objects used by the Controller and DIA to gain a more explicit orientation from the other(s) towards a particular event or activity, are carefully designed to encourage a particular form of co-participation from a colleague, but rarely demand the other's attention. They allow the individual to continue with an activity in which they might be engaged, whilst simultaneously inviting them to carefully monitor a concurrent event." [10, p.81].

Mutual awareness is based on the performance of clues and signals for coordinative purposes in the course of the work. According to Schmidt [15, 17] a range of workplace studies (e.g.[8, 10, 21]) that investigated how mutual awareness is produced and maintained by members of the cooperative ensemble have demonstrated that mutual awareness does not occur effortlessly. As described by Heath & Luff it involves the performance of cues and clues 'designed to encourage a particular form of co-participation from a colleague'. It does not simply happen by 'being there'. Mutual awareness is *produced*, that is, it is a second order effort performed to coordinate cooperative work. Perhaps we could suggest that mutual awareness may be 'inexpensive' or 'cheap' coordination compared to other modes of articulation work; however, it is not coordination 'free' of second order effort. In relation to this perhaps we could ask: Are practices of stigmergy coordination 'free' of second order efforts?

Recall how, the actors created design sketches and transposed them to CAD drawings for tendering purposes, and how the tendering project in turn was projected onto working plans. In this building design process, an actor changes the form of a geometrical representation of the building's design, not for the purpose of conveying a message, but simple as a part of design work; another actor notices this, and in turn acts directly upon this change of state. Here, no extra effort is made solely to coordinate and yet the cooperative effort is aligned and integrated. Perhaps we could suggest that stigmergy is coordination without second order effort.

In sum, perhaps we could express the relative economy of second order effort in the following manner: Crudely put, if elaborate articulation work is 'expensive' and mutual awareness is 'cheap' then stigmergy is 'free'.

The logic of practices of stigmergy

At this point we could ask: Why do the various actors distributed across the taskscape continue the work on representations performed by other actors – why not begin from scratch? For example, the design of the working plans is carried out as a direct elaboration of the previously created tendering plans. The tendering plans, as conveyed to the potential contractors, stem from the representations created in the design phase.

One (obvious) answer is that from the point of view of the individual actor it is more practical to continue the work on representations made by other actors, because it mostly requires less effort than the alternative, beginning from scratch. However, we could argue that there is more to it. These practices also have an integrating and coordinating effect as described above. Perhaps beginning from scratch is not a real option, we could speculate, because it risks breaking the continuity of the design process. That is, if the previous work was not taken into account, it would probably be entirely impossible to create the working plans, for example: the complexities of creating the highly detailed working plans would be overwhelming without less complex representations to build on. We could suggest that the gradual increase in the complexity of the representations makes the design process more manageable in the sense that it reduces the overall complexity of representing the building by allocating the process to a series of interrelated steps or stages.

In addition, the affordances of a particular type of artifact mostly seem to meet the demands of a particular position in the taskscape. For example, the open and imaginative nature of sketches meets the demands internal to the task of making up the conceptual design of the building. To architects, their sketchy and informal representations capture the mixture of symbolic richness and abstraction, which allows them to express qualities of space, light, atmosphere, and materials [20, p.12]. The sketches are highly theatrical; they use the language of 'artistic impurity, hybridity, and heterogeneity' for communicating certain ideas and qualities of an object. As mentioned, one feature of these informal representational artifacts is their openness to extensions, modifications, and novel interpretations [20].

Compared to sketches, the more accurate and generally less ambiguous CAD models are better suited to the task of creating the tendering material or the working plans. According to Harris [9], drawings of a technical nature often rely on having the space divided in a predetermined way so as to make the significance of a graphical form depend partly on the absolute position it occupies within that space [9, p.123]. Drawings of scale such as CAD drawings are based on this principle. That is what makes it possible to calculate, for example, the exact size of a room measured in square feet or the distance from pavement to roof. CAD plans made for construction purposes are mapped to a coordination system referred to as 'module lines'. Moving a particular graphical element, for example the representation of a wall, in relation to these module lines will have an alternating effect - for example changing the size of a room. Perhaps we could suggest that the same commitment to scale and precision is not found in what is described above as informal imaginative and open sketches.

Following this discussion of the affordances of various types of representational artifacts we could suggest that different affordances are required of representations at different positions in the taskscape. For example, the requirements of conceptual design prompt the employment of sketchpads on the part of the architects creating the design concept; analogue to this, the requirements of the tendering project or the working plans induce the actors to rely on CAD applications rather than sketches, for example. The sketches and CAD models, described above, are not interchangeable at a given position in the taskscape due to their vastly different affordances. This may be part of the reason why certain types of representation are employed at certain positions in the taskscape and part of the reason why actors are compelled to permutate the representational artifacts through practices of stigmergy involving the characteristic inheritance of content from one type of artifact to another and the derived coordinative effects.

In sum, as progressing is made from one position in the taskscape to another representational artifacts are created, elaborated and merged through practices of stigmergy. These practices are partly prompted by the discrepancies between the affordances required of representations at different positions in the taskscape, and partly in order to reduce the complexity of the design process by allocating the process to a series of interrelated stages. This could be dubbed the 'logic of practices of stigmergy' in relation to architectural design.

THE CHALLENGE OF PRACTICES OF STIGMERGY FOR CSCW

We have argued that in addition to being coordinated through articulation work, cooperative work in a building design project is coordinated through practices of stigmergy or what could perhaps be described as 'tacit' coordination. Tacit in the sense that the actors involved in the design process coordinate their cooperative work without any second order coordinative effort. Moving from one drawing to another, from low level detailing to high level, from one stage in the design process to the next, the actors partly rely on their material field of work for orientation and action. That is, actors in part coordinate and integrate their cooperative efforts by acting directly on the physical traces of work previously accomplished by themselves or others. This is what we have described as practices of stigmergy.

The challenge for CSCW emerging from this is the fact that stigmergy is practiced in a cooperative process. How can we reduce the cost and increase the reliability of this distributed process of coordinating and integrating of cooperative work?

Finally, practices of stigmergy are highly composite practices, consisting of interrelated artifacts made for different purposes in accordance with the shifting demands of the taskscape. This raises non-trivial technical issues of interoperability, as digital and non-digital artifacts such as sketches of various kinds, physical models, and CAD models are incorporated in these complex practices. How do we support the combination and merging of representational artifacts in practices of stigmergy in cooperative work?

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