Proxemic Transitions:
Designing Shape-Changing Furniture for Informal Meetings

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Figure 1. Shape-changing furniture with interactive surfaces allowing people to change proxemic arrangements by gradually transitioning between tabletop and wall display configurations.

ABSTRACT

The field of Shape-Changing Interfaces explores the qualities of physically dynamic artifacts. At furniture-scale, such artifacts have the potential of changing the ways we collaborate and engage with interiors and physical spaces. Informed by theories of proxemics, empirical studies of informal meetings and design work with shape-changing furniture, we develop the notion of proxemic transitions. We present three design aspects of proxemic transitions: transition speed, stepwise reconfiguration, and radical shifts. The design aspects focus on how to balance between physical and digital transformations in designing for proxemic transitions. Our contribution is three-fold: 1) the notion of proxemic transitions, 2) three design aspects to consider in designing for proxemic transitions, and 3) initial exploration of how these design aspects might generate designs of dynamic furniture. These contributions outline important aspects to consider when designing shape-changing furniture for informal workplace meetings.

ACM Classification Keywords

H.5.3 Information Interfaces and Presentation (e.g., HCI): Collaborative Computing

Author Keywords

Proxemic Transitions; Shape-Changing Interfaces; Augmented Furniture; Interaction Proxemics; F-formations

INTRODUCTION

This paper investigates how the theory of proxemics [17] might inform the design of shape-changing furniture with interactive surfaces. Shape-changing furniture opens up new possibilities in designing for dynamic social situations such as informal meetings. Interaction proxemics articulate how properties of interactive devices inherently serve to configure people in spatial ways with respect to the technology, content and each other [29, 27]. As mentioned by Leithinger et al. [21], what is particularly interesting about shape-changing furniture is the spatial dynamics that they enable, and we particularly explore what these dynamics enable for informal workplace meetings. Through an empirical study of a workplace with highly collaborative work practices, we explore the nature of the socio-spatial transitions in collaboration and we envision how shape-changing furniture can offer new opportunities for collaboration through its ability to shift spatial configurations and accommodate for shifting social situations. Insights from this work is coined in the notion of proxemic transitions. Design of interactive shared surfaces, such as digital tabletops [36, 37, 47], wall displays [7, 41, 39, 43], and combinations hereof [45, 47, 48] is an active research area in exploring new ways of orchestrating collaboration through technologies. Studies of shared displays have shown that vertical and horizontal surfaces have different properties in how they support collaborative activities [34]. Even though these shared displays hold unique properties in supporting group dynamics, they rarely accommodate shifting physical constellations. Only recently, attention has been drawn to the opportunities

for shape-changing surfaces to support collaboration [41, 42, 40]. Furthermore, recent work on shape-changing interfaces explores the combination of physical shape change and digital projection and animation, bringing attention to how dynamic properties of the physical and digital may complement each other [23, 22, 35, 5, 12].

In this paper, we use a Research-through-Design approach [20], where the design work draws upon theories on prox-emics and iterations between design explorations and empirical studies of a highly dynamic work environment. Based on recurring scenarios of the informal meetings observed, the dynamic surface was designed to enable a group of people to maintain shared space, while switching between the vertical, horizontal, and in-between configurations around a shared surface. In this way we explore how a shape-changing surface can provide improved flexibility in supporting informal meetings. The prototype can transition between being an interactive table and a wall surface, and a range of states in between (see figure 4). With the design we investigate the qualities of having dynamic horizontal and vertical surfaces in supporting the multitude of ways people enact spatial relations during informal meetings. Further, we explore how user interface transformations and physical transformations complement each other. The design explorations have led to defining the notion of *proxemic transitions* as a design concept for shape-changing furniture. Proxemic transitions has served as the conceptual glue [30] and nucleus of the research interest [20] in how it links together empirical and constructive solutions on dynamic furniture. The paper highlights three aspects of proxemic transitions – namely *transition speed*, *stepwise reconfiguration*, and *radical shifts* – all three tying together the dynamics in proxemics and the spatial qualities of dynamic surfaces. In this way we contribute with the following: 1) the concept of proxemic transitions for articulating a possible design space for shape-changing furniture in workplaces, 2) an outline of three qualities to consider in such designs, and 3) a novel prototype exploration for envisioning shape-changing furniture and its spatial qualities in a workplace setting.

RELATED WORK
This paper relates to a substantial body of work that spans multiple areas of inquiry, including design of novel shape-changing interfaces, interactive surfaces, workplace studies and proxemics theory.

Shape-Changing Interfaces
Shape-changing interfaces is an interdisciplinary research field bringing together competences from design, art and computing in exploring the potential of physically dynamic artifacts [33, 35, 21]. Rasmussen et al. [33] have proposed a taxonomy for articulating the design space of shape-changing interfaces. The paper highlights key challenges for the field, including moving beyond point designs, and argues that future work within the field should use a systematic approach in exploring the design space by combining purpose with shapes and transformations [33]. Our work takes up this challenge in exploring design of furniture-scale shape-changing interfaces with the purpose of supporting informal meetings. A few examples of shape-changing furniture and room elements have emerged

recently [21, 40, 16, 42]. In the work domain, the subjects of study have ranged from dynamics regarding ergonomics, privacy and variable group sizes [41, 21] to dynamic shapes in relation to task performance [40]. Few have explored how shape-changing interior can facilitate collaboration [42, 40]. Selected work within shape-changing interfaces explores the combination of physical shape change and digital animation using spatial augmented reality [23, 22, 35, 5, 12]. Common for this research is the investigation of how properties of physical transformation and pixel displays can complement each other. We build upon the work of Lindlbauer et al. [23] who compare virtual and physical transformation on a combined augmented reality and shape-changing tablet-sized object. They compare the transformations in relation to the property speed, stating that physical transformations are limited in speed by the physical constraints of the actuators in the object, whereas pixel animations are only limited by the frame rate. Our work seeks to explore how this aspect of transformations (among others) compares in the two paradigms for supporting the dynamics of ad-hoc collaboration.

Interactive Surfaces and Spatial Configuration
Spatial properties of physically static interactive surfaces and their impact on collaboration have been widely studied in HCI. In particular tabletop and wall displays have formed the locus of attention, but also augmented furniture considered more widely [39]. Prototypes have illustrated how orientation [37] and territories [36, 31] can serve as means for coordinating. Scott et al. [36] found that when people collaborate around tabletops they organize in the interactive space in *personal*, *group* and *storage* territories. The concept of territoriality relates to Hall's Proxemics notion of distance zones and personal space. We make use of these concepts and principles in the design of the dynamic surface prototype. In addition, our investigation builds on studies of how the spatial configuration of displays matter. Studies have illustrated how different physical display configurations in public space have implications for crowd sizes and social learning [43]. Rogers et al. [34] compare impact of vertically or horizontally oriented displays concluding overall that tabletop displays are good at supporting cohesive collaboration amongst groups of up to 3-4 people whereas wall displays are superior for changing group sizes and when dealing with information which is being primarily shown to participants. This work is highly motivational for our research and we contribute with investigating how dynamic surfaces can serve to enable these properties in an ad-hoc fashion during informal meetings.

Workplace Studies and Collocated Interaction
Multiple studies within computer-supported collaborative work (CSCW) have discussed how spatial organisation and layout affect awareness and coordination, local mobility and collocated work practices [24, 8, 6, 11]. In the early work, stationary computers, screens and telephones forced workers to move between equipment, stations and rooms throughout their activities. Luff & Heath [24] introduced the term *ecological flexibility* to characterise how well artifacts and technology supported spatial adaptation. Whereas paper documents easily follow the work and affords sharing, reorientation, folding,

annotation, etc., the stationary computers required work to be relocated. Today, mobile computing has increased the ecological flexibility, but other aspects of the physical environment still require people to adapt throughout their activities. Birnholtz et al.'s [9] study on privacy and awareness in a work environment show the importance of local mobility and proximity in coordination and awareness. Not surprisingly, workers used moving into proximity as a way of creating attention prior to initiating interaction, and as a way of judging whether the interaction would be convenient to others. Similarly, in a study on social dynamics and spatial work practices in open office spaces, Bjerrum & Aaløkke [10] found that collocated ad-hoc collaboration and informal meetings played an important role in everyday knowledge sharing and collaboration. We have adopted their focus on informal meetings and their notation in analyses of spatial dynamics.

Proxemics and F-formations

Hall's [17] theory of proxemics has gained attention in the HCI community for his accounts of how people use space for enacting their social relations [4, 14]. Proxemics is often complemented with Kendon's [18] theory of F-formations describing a range of spatial patterns in group formations. Together, these social theories provide a useful language for understanding and designing for social situations involving collocated people and shared artifacts. The theories have been used to suggest new approaches to ubiquitous computing with Greenberg et al.'s *proxemic interactions* [14] (e.g. [3, 4, 25]), and analytical work aiming at deriving broader implications for novel interaction paradigms (e.g. [26, 29, 27, 38, 15]). Our work is related to Greenberg et al. [14], however, it provides a different design approach building on the notion of interaction proxemics [27, 29]. Where Greenberg et al.'s notion of proxemic interaction [14] seeks to operationalise users' spatial configurations to become a means of interacting with technology, interaction proxemics [27, 29] emphasises how the specific properties of interactive technology influence users' opportunities for configuring themselves with respect to each other. In line with this, Mentis et al. [27] and Morrison et al. [28] provide findings regarding how physical properties of interactive artifacts have implications for how people can arrange for discussions and collaborations. These insights can be used to understand how some properties work well whereas others impede people's abilities to collaborate. These insights have driven our theoretical concept of proxemic transitions emphasising how physically dynamic artifacts can provide new opportunities for configuring the environment to support informal collaboration.

PROXEMIC TRANSITIONS

The theory of proxemics [17] has inspired our perspective on shape-changing furniture. Hall describes how certain features of a space either support or inhibit a certain type of social behaviour. He distinguishes between fixed- and semifixed-feature space, where buildings represent fixed-feature space, while furniture or other potentially movable artifacts represent semifixed-feature space [17]. Our vision for shape-changing furniture is inspired by Hall's descriptions of the relationship between semifixed-feature space and human behavior. Accounts from an experiment in a hospital define rooms that

tend to keep people apart as *sociofugal* space and rooms that tend to bring people together as *sociopetal*. What particularly motivates our work is the goal of spatial flexibility [17, p.110]:

> "...sociofugal space is not necessarily bad, nor is sociopetal space universally good. What *is* desirable is flexibility and congruence between design and function so that there is a variety of spaces, and people can be involved or not, as the occasion and mood demand."

O'Hara et al.'s concept of interaction proxemics [27, 29] emphasizes the need for considering proxemics in design of novel interactions. Mentis et al. [27] provide a great example of how the theories of proxemics and F-formations can come together and help articulate spatial properties of interaction designs and their social implications. In a study of collaborative practices in neurosurgery, they highlight three dimensions of proxemics that are important to consider in collaborations involving shared displays – namely *control proxemics, deixis proxemics* and *perceptual proxemics*. These accounts are in line with Hall's arguments about how features of a space either support or inhibit certain social behaviour. Morrison et al. [28] highlight the role of F-formations and the ergonomics of horizontal and vertical formats in facilitating or hindering group use of patient records. Both studies show how physical setup of the technology may impede the ability to collaborate.

Building on this work, our design explorations revolve around understanding how shape-changing furniture with dynamic horizontal and vertical displays might support proxemics and F-formations for collaboration. We envision shape-changing furniture that enable collocated collaboration around the same shared artifact, while participants can switch between the affordances of different spatial configurations. Through the design of a dynamic surface, we explore the question of what it might bring to the interaction proxemics of informal meetings that displayed content can transition between hybrids of a horizontal and vertical surface. We found that people organize and negotiate space to optimize their proxemic relations regarding deixis, control and perception, similar to findings by Mentis et al. [27]. The focus of this paper is on designing for *the act of organising and negotiating space* with dynamic furniture. To emphasize this focus we coin the term *proxemic transitions* to extend the conceptual framework of interaction proxemics. A proxemic transition is defined as an event involving at least two people negotiating a change in spatial arrangement, i.e., either arranging in a certain F-formation around content or spatially reconfiguring or reorganising artifacts in the surrounding environment. To clarify what we mean by *reconfiguring*, we distinguish between (1) *adapting*, i.e. adapting one's posture or position in relation to the situation, and (2) *reconfiguring*, i.e. spatially reconfiguring objects in the environment. Both types of behaviour are considered proxemic transitions given that proxemics are enacted in an interplay between collocated people's bodies, physical artifacts and semifixed features that constitute the shared space. The purpose of the present work is to understand opportunities in designing for the latter. We explore the potential in combining physical transformations with shape-changing interfaces with digital transformations. In particular, we demonstrate with a dynamic surface how the

spatial dynamics of both digital content and physical shapes complement each other in providing a flexible space for collaboration and interaction proxemics. The concept of proxemic transitions is unfolded in this paper by bringing attention to three aspects of people's transitions and how digital and physical transformations can support this.

RESEARCH APPROACH

The work presented here follows a Research-through-Design (RtD) approach [49, 13, 20]. Empirical studies of informal meetings in an open office environment have alternated with the design of dynamic surfaces in a mutually informing process of knowledge production. In this work, the concept of *proxemic transitions* serves as an integrative concept that bridges between the empirical study and the design work. The nature of typical informal meetings and design qualities of shape-changing furniture have been tied together in this theoretical concept which has formed the nucleus of research interest (see [30]).

Design activities involving provisional artifacts of dynamic surfaces have enriched and deepened the concept of proxemic transitions in an accumulative fashion [20]. This approach has allowed for freedom of exploration while promoting transparency in the design process. As described in [30], the objective of the provisional artifacts is not the construction itself, but the theoretical development of proxemic transitions that it manifests. In the lab, we built an initial prototype of two pivoting table surfaces that could be repositioned in relation to each other to try out how spatial dynamics were experienced in different physical configurations. Initial explorations involved considering how different configurations allowed for transitioning between personal and social space, i.e. transitioning in proxemics. The prototype supported thinking through designing and allowed for experimenting with a larger set of different configurations and form factors.

In parallel to the design work, we studied informal meetings in an open office of a local software and web development company. This place was selected since they have over the past years worked carefully to set up their open office environment in project-structured zones to support tightly coupled collaboration between software developers. Two of the authors spent a total of 20 hours (during two visits with 26 days in between) in the workplace. The focus was to understand transitions in their collaborative work. We conducted observations of detailed transitions between individual work, informal coordination and smaller episodes of collaboration. Given the perspective of proxemics, we took detailed notes on how their spatial practices around collaboration formed in the context of the physical environment. Inspired by the spatial notation technique of snapshots [10], we captured spatial behavior (see figures 6 and 7). The field notes were supplemented with photos and video when possible. In addition, we conducted four open-ended interviews. The collected material was compared and synthesised by two researchers into patterns of typical scenarios and important qualitative examples were analysed in terms of their interaction proxemics and proxemic transitions.
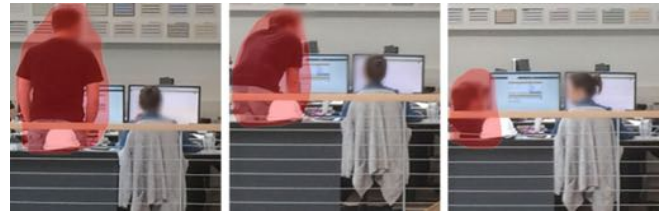

Figure 2. A proxemic transition into a longer-than-anticipated meeting with a colleague. The man to the left adapts his body posture to the environment and the duration of the meeting when he gradually moves from standing (left), to leaning (centre), and finally into squatting (right).
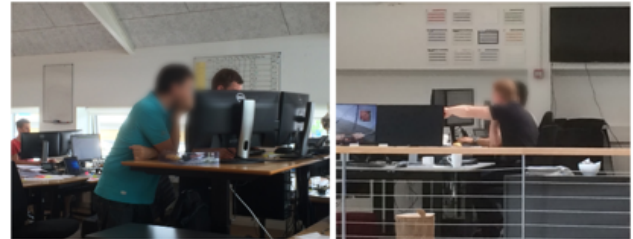

Figure 3. Two variants of sustained informal meetings. A pair both standing (left) and a pair both sitting (right).

COLLABORATION AND SHAPE-CHANGING FURNITURE

The lessons from the studies of collaboration in open offices gave context to our initial design explorations. They further provided empirical motivation for the potential of shape-changing furniture. We found that even though coworkers each have their personal desk spaces, *informal meetings* play an important role in their everyday work practice. People continually transition between individual, pair and group work from minute to minute and sometimes even second to second. In particular, we observed how coworkers frequently move between personal workstations (with stationary computers equipped with large screens) to colleagues' desktops. Activities involved making verbal exchanges of small bits of information or discussing something by referring through pointing to content on a colleague's display (see figure 3, right). There was a high frequency of one-to-one interactions as a form of coordination work reemphasizing the importance of local mobility for collaboration [24]. Local mobility was well supported by the physical open office space, where the personal desks are arranged in groups of four (see figures 6 and 7), with additional chairs available for collaborative activities in smaller groups. While coworkers very frequently transitioned between personal work and informal meetings at various durations, we found their mobility to be in sharp contrast to the inflexibility of stationary computers. The insights from the workplace study fed into the prototyping sessions with dynamic surfaces in the form of typical scenarios. Analysis of interaction proxemics and F-formations provided ideas for supporting people's spatial behaviour in collaborations.

Initially, we conducted body-storming sessions with the first prototype iteration of two individual table surfaces capable of rotating horizontally (as opposed to the vertical screen rotations in [41]. This allowed us to experiment with various physical spatial configurations and projected digital contents while still learning about the physical constraints of a furniture-

Figure 4. Five example positions of the dynamic surface prototype. Vertical movement from the linear actuators are translated into a pivoting movement that lifts the plywood arms and lifts the hinged table surfaces.

scale shape-changing artifact that did not reveal from abstract sketches. The explorations involved manipulating with *orientation* and *scale* of displayed content and the physical surfaces over time. The prototype setup enabled rapid prototyping of physical and digital transformations/animations to compare their respective qualities in terms of proxemic transitions. As a result of our second visit to study informal meetings, we learned more about the challenges in supporting proxemic transitions at the workplace, and hence the potential of shape-changing furniture in this context. Identifying typical scenarios we found that there were clear patterns in the duration of meetings, and that the duration was rarely planned in advance. For sustained meetings people would seek to continuously adapt and reconfigure to support the activity under the constraints of the current conditions, e.g. often passers by would lean over the table resting on their arms or squatting to make the digital contents equally accessible for the two people (see figure 2). Currently, the individual workplaces made it challenging for more than two people at a time to see the details of digital contents on the screen (see figure 3).

We built a refined prototype, enabling smooth physical and digital transformation that allowed for exploring and enacting conceptual scenarios addressing the challenges outlined above. This includes addressing 1) different timings of informal meetings, 2) gradual reconfiguring of semifixed features in response to prolonged sessions, and 3) radical reconfiguring of semifixed features in response to shifting activities and number of participants. Together these findings motivate our design explorations of three design aspects of proxemic transitions manifested in our provisional artifact.

AN AUGMENTED DYNAMIC SURFACE

The prototype is a shape-changing surface augmented with displays using spatial augmented reality. The design is inspired by the notion of interaction proxemics [29, 27] in how it provides a flexibility for people to organize around shared display content in a physically dynamic way. The surface transforms between vertical and horizontal configurations, ranging from being in a fully horizontal "table" configuration to a fully vertical "wall" configuration. During the transformation between the two endpoints, the prototype can take a hybrid "table + wall" configuration similar to BendDesk [45] and Curve [48]. Changing between these configurations shifts the proxemics in regards to how a group of people can naturally organize around furniture for pointing to (deixis), controlling and perceiving the displayed content. The prototype serves as a token for envisioning and experimenting with shape change in informal meetings through the notion of proxemic transitions.

The dynamic surface consists of two parts held together by hinges. The table surfaces are fixed on top of two Linak™ linear actuators positioned side by side. When the actuators are in the maximum position, the table surfaces literally hang in a vertical configuration. As the actuators move downwards, the construction translates the vertical movement by the actuators into a pivoting motion that slowly moves two plywood arms from a vertical to a horizontal position, supporting the rising surface (see figure 4). The hybrid "table+wall" configuration is achieved by pausing the movement as the table is moving into a horizontal position. Here the lower table half rests on the support arms while the upper half rests on the top of the actuators in custom mounting brackets. The virtual graphics are projected onto the shape-changing desk through spatial augmented reality using a single projector placed above the desk. In order to do dynamic projection mapping during shape changes, each table surface is tracked using OptiTrack [1]. Digital content is displayed through an application built with the Unity3D game engine [2]. This application receives real-time user inputs through OptiTrack to detect physical transformation of the furniture as well as collisions between users' hands and the furniture surfaces for simulating touch events. Currently the physical shape of the desk is controlled with a button press by a user. Since the focus of the paper is on explorations of the proxemic qualities of shape change, self actuation is not part of the scenarios with the dynamic surface. However, future iterations will provide an API for controlling the desk such that the balance between user control and self actuation could be explored in detail, as proposed in [32]. Surface textures in Unity3D display a web view that points to the URL of a web application, enabling the user interface to be implemented with web technologies (JavaScript, HTML5, and CSS3). The user interface consists of *territories*, which are content areas with a color associated with a user (see figure 5 for overview). Each territory contains a *rotation button* (for rotating its contents) and a collection of *documents*, e.g. PDFs or images, that can be flexibly reorganized and moved around. Territories can overlap, enabling documents from different users to be spatially distributed across the entire surface area of the physical prototype. The web application utilizes the web infrastructure of *Webstrates* [19]. This enables a simple way of connecting across devices, so that mobile devices can easily interact with the content on the surfaces of the shape-changing surface by communicating through a server. A mobile interface can be used to control the visibility of the content presented on the dynamic surface, enabling a user to quickly toggle on/off a view to personal content.
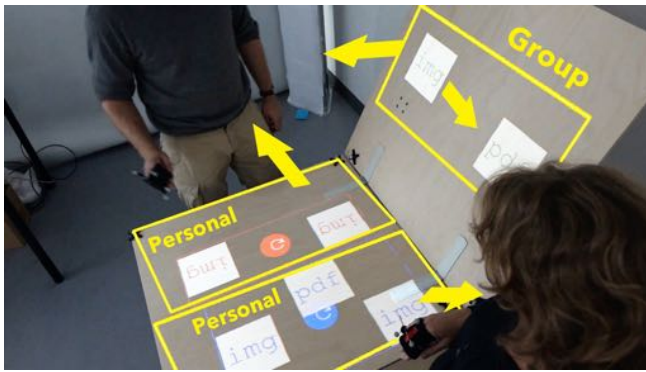
Figure 5. An overview of the dynamic surface's user interface. Digital documents are organized within a territory marked with a dotted line in a personal color with a button in the middle of the territory for rotating its content.

DESIGN ASPECTS OF PROXEMIC TRANSITIONS

Our iterative Research-through-Design process – involving design explorations with the dynamic surface based on empirical examples of informal meetings – enabled us to unfold and articulate aspects of the design space. Our work elicited three design aspects of proxemic transitions.

1. **Transition speed:** The duration of a particular informal meeting has implications for the kinds of transitions people will make. Quick exchanges require support for high-speed transitions that involve a low transactional cost [27], whereas sustained informal meetings would benefit from more ready-at-hand tools for reconfiguring the physical space for digital content display, like being able to change the height or the shape of a surface.

2. **Stepwise reconfiguration:** Informal meetings are spontaneous and not planned out in advance, implying that participants *adapt to* or *reconfigure* the spaces they engage with in a gradual and stepwise manner as they move in and out of group and personal work. This can be designed for in shape-changing furniture by carefully designing the trajectory of its transformations with meaningful steps between its endpoints.

3. **Radical shifts:** In informal meetings it is not necessarily known beforehand whether the nature of the activity will shift, by e.g. the meeting going from containing two to five people within few minutes. Dynamic surfaces have the potential for accommodating a variety of activities and group sizes in its abilities to radically scale up/down or reorient the display area for digital content.

The design aspects are related to the temporal dimension of collaboration in that they describe the dynamics in physical space that revolve around informal meetings. *Speed* is about the nature of a transition either towards, within or away from a meeting, *sequences of reconfiguration steps* involve the nature of adaptation and step-wise reconfiguring the environment within a meeting activity, whereas *radical shifts* typically happen on a larger time scale when new people enter or when the activity otherwise changes in nature, e.g. from design work to programming. The following sections synthesize our understanding of the design aspects of proxemic transitions as it has

developed. For each design aspect of proxemic transitions we account for how it manifested in the observations of the workplace study articulated in terms of snapshots [10], interaction proxemics [29, 27] and F-formations [18]. In addition, we demonstrate and reflect on a corresponding scenario with the dynamic surface prototype on how shape-changing furniture could support this aspect of proxemic transitions.

Type of meeting	Duration	Typical behaviour	Group size
Quick	<1 min	Talk across space, roll over.	2
Ephemeral	<5 mins	Roll over, walk over.	2-5
Sustained	>5 mins	Squatting, lifting table, or grabbing guest chair.	2-5

Table 1. Durations of typical informal meeting situations from observational study.

TRANSITION SPEED

The observational study indicated that the nature of informal meetings could often be distinguished by their *duration*, i.e., for how long the knowledge sharing and collaboration usually lasted before the participants moved on to other activities. Table 1 provides an overview of what we found to be typical informal meeting situations. As stated in the table, observed situations could roughly be divided into *quick exchanges*, *ephemeral meetings*, and *sustained meetings*. The examples indicate how the open space allows for *quick exchanges* in the office islands. The work stations right next to each other enabled quick transitions between personal and group work (see figures 6 and 7) in an ad-hoc manner. Figure 6 is one example of behaviour that can be characterized as a quick exchange, where two people sitting next to each other can make quick and frequent transitions between personal work and short exchanges. Other examples include talking to a colleague sitting across from you behind your displays or quickly walk over to leave a verbal message. Analysing the situation of figure 6, the proxemic transition is a very quick and temporary exchange, usually indicated in A's body language. In such situations, participants are reluctant to make more radical physical transitions like rearranging the space, as that type of behavior would signify a different kind of transition than what was intended by A. *Ephemeral* and *sustained meetings* often involved adaptation and reconfiguration in a number of ways. As illustrated in figure 7, where one person had tightly coupled collaborations with the colleague across. The perceptual proxemics of this situation imply that one would have to walk around in order to have shared visual access. In a "standing and sitting" formation as in figure 7(right), one is standing implying a more ephemeral exchange. The sustained informal meetings usually involved using the established physical configurations with either two seated next to each other or standing next to each other confronting a screen (see figure 3). We also observed examples of sustained meetings where colleagues would either adapt their postures around screens or would come to a point where they temporarily reconfigured the ergonomics of the environment by pulling over guest chairs or lifting the tables mechanically for a stand-up meeting. The proxemic transition in figure 2 shows a sustained meeting from the study. It exemplifies how coworkers adapt their
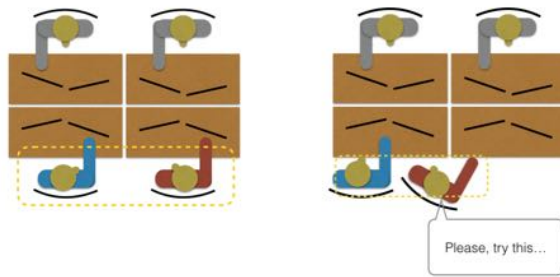
Figure 6. A quick transition scenario where person A (red) physically moves between her own (left) and B's (blue) personal work space to form a "2 sitting" configuration (right).
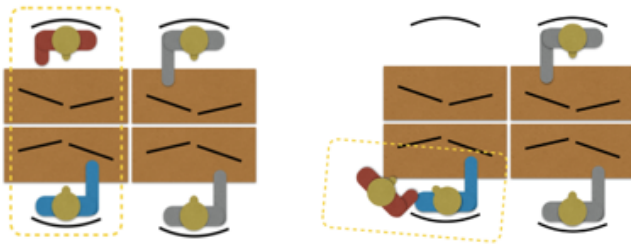

Figure 7. A transition scenario where A (red) physically moves between her own (left) and B's (blue) personal work space to form a "standing and sitting" configuration (right). This usually would manifest as an ephemeral meeting.

posture to the environment and change the proxemic relation to a colleague. A man is standing next to a colleague's workstation initiating a discussion on a topic involving contents on the colleague's screen, then starting to lean on the table, and eventually squatting in front of the table to be at eye level with the screen and the colleague. The dynamic is typical for a discussion involving displays. Prolonged discussions might cause physical strain on the standing colleague due to the configuration of the desk and display – circumstances that (in the example) make the colleague on the left change posture. Hence, the above examples indicate that the temporal nature of informal meetings has implications for which proxemic transitions might occur. In the following, we consider how this can be supported by shape-changing furniture.

Transition Speed in Dynamic Surfaces
The design space of shape-changing furniture enables us to rethink the way people can get into place for collaborations by providing new mechanisms of organizing space. The three types of informal meetings relating to the duration of meetings and speeds of transitioning can help us design for this aspect of proxemic transitions. With the dynamic surface, *speed* is considered carefully in its ability to support both quick transitions through digital spatial transformations and more radical transitions through physical transformations. Inspired by research on speed in shape-changing interfaces with projection mapping [23, 35] and the large diversity in types of informal meetings, the following scenario with the dynamic surface seeks to illustrate how we can design for different transition speeds. The following scenario contains a quick informal exchange and a prolonged exchange.
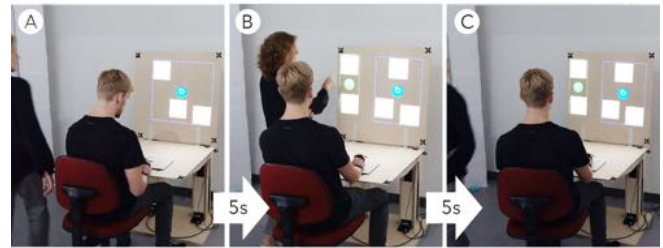

Figure 8. The dynamic surface supporting quick exchange: The digital space is reconfigured to accommodate two users. (A) Bob works at his personal desk as Alice approaches. (B) Bob invites Alice by bringing his content to the side, and Alice brings in her content to quickly convey an idea to Bob. (C) Alice leaves and Bob can go back to personal work (now with a digital copy of Alice's idea).

Quick exchange (see figure 8): Alice and Bob are doing individual work on a shared project at their personal workstations. They are both evaluating notes and pictures from a large field study. Alice has some questions to the study, and she walks over to Bob to ask for his opinion. Bob opens up a digital space on the display, and using her mobile device Alice quickly brings up a photo in the periphery of Bob's vertical display surface (see figure 8(A-B)). After Bob has expressed his opinion, Alice returns to her seat.

Sustained meeting (see figure 10): Tom arrives at Bob's desk because he has finished a draft of his collection of tagged photos (see figure 10(A)). Bob is nearly ready too, and they decide that they want a bit more space, such that they can have their personal stuff at the desk, while sharing a larger display area for collaborating (see figure 10(B)). Tom and Bob can now organize their photos and sketches together in a larger space, while being able to maintain each their personal space.

In the above scenario, the situation in figure 8(A-C) requires Alice to walk up next to Bob in order to create a formation with perceptual and deixis proxemics [27] where they can easily face each other while accessing a shared display. However, the significant quality of the first interaction is how it involves a certain type of *loosely coupled* collaboration. For quick exchanges, shape change could be inappropriate. Alice's intention is not to reconfigure the environment for a discussion, but rather getting a quick response in order to continue her work. Notice how speeds of transitions are annotated in figures 10 and 11, respectively. This shows how the dynamic surface provides a low transactional cost [27] in digital transformations that only require a few seconds, while the physical transformations involving shape change occur at a lower speed and have a higher transactional cost – only valuable to some types of informal meetings. We refer to the video [1] for getting a clearer sense of how speeds of physical vs. digital transformations are experienced.

STEPWISE RECONFIGURATION
The second design aspect of proxemic transitions is *stepwise reconfiguration*, i.e. how people gradually change their circumstances for collaborating during informal meetings in small

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[1]See the video accompanying this paper.

steps. The nature of informal meetings is that they are unplanned, and they occur frequently and spontaneously. Physical transformations, such as moving up and down the table, are limited to a certain speed and this has implications for how people might either adapt to or reconfigure their environment. The main point of the following examples is that involved participants make ad-hoc adaptations and reconfigurations to the situation while not being entirely clear in advance how the informal meetings will evolve. A series of snapshots from a time period of only 5 minutes in figure 9 illustrate that along with the speed with which knowledge exchanges occur, people's stepwise adaptations and reconfigurations are an important aspect of the nature of proxemic transitions. People adapt their positions to better align with whom they are in conversation with, and this occurs in an ad-hoc and unplanned manner that involves multiple steps progressing towards a negotiated resting situation for their conversation. These spatial negotiations occur as a parallel activity while attention is on the conversation. A particularly interesting snapshot from the field notes reveals a situation with spatial negotiations involving multiple parallel informal meetings.

> As coworker A was away from his workstation, coworker C came by to talk to coworker B while A was away. He borrowed the free chair, and once A came back again, A and C had a quick exchange, and A just lifted his table, so B and C could continue their sustained informal meeting.

This illustrates very well a characteristic of the ad-hoc behaviour revolved around informal meetings, namely how people use certain mechanisms in semifixed-feature space, e.g. borrowing a chair for quick transitions, whereas the more radical, such as e.g. lifting a table, is used as a workaround when it is necessary to stand because one's chair is being borrowed. This example contrasts the example of a colleague squatting for a one-to-one prolonged discussion in figure 2 in that one is about adapting one's posture and the other is about reconfiguring the environment. However, both involve transitions that aim at changing the physical circumstances for collaboration, i.e. organizing for certain interaction proxemics. Together these examples pose a challenge for how designers can support proxemic transitions, in that a) due to the ad-hoc nature of informal meetings the progression cannot be predetermined, and b) the spatial reconfigurations are complex and socially situated, implying that – rather than alone designing for radical end-to-end transformations – stepwise reconfigurations must be enabled in shape-changing furniture.

Stepwise Reconfiguration with Dynamic Surfaces

The following is motivated by proxemic transitions ending with one in a squatting position (figure 2) or a gradual rearrangement of furniture (figure 3) as described in the above empirical examples. We explore how opportunities for new proxemic transitions might be enabled by shape-changing furniture, providing the possibility to choose different spatial ways of progressing and sustaining informal meetings. Not knowing in advance how long an informal meeting will take might prevent one from radically reconfiguring the environment. Being able to decide on stepwise smaller improvements rather than making radical changes to the physical environ-
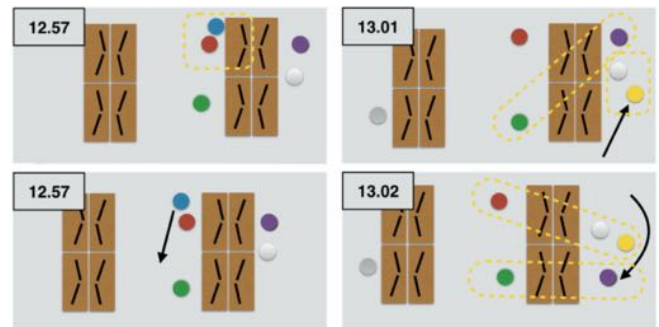

Figure 9. Stepwise adaptation. *12.57:* **People doing individual work, while red and blue are in dialogue.** *13.00:* **As blue moves back, red puts on headphones to focus.** *13.01:* **Green and purple initiate a dialogue, while another starts between white and yellow.** *13.02:* **Purple leaves his desk to be able to talk to green without interfering with the others. Red could eavesdrop the conversation between white and yellow and joins.**
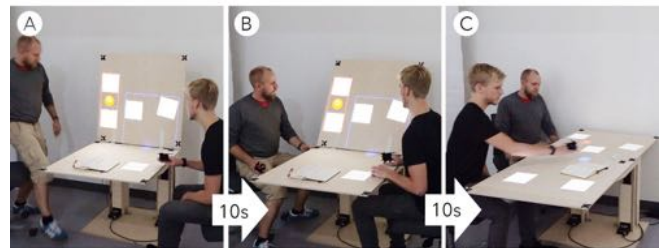

Figure 10. The dynamic surface supporting ephemeral/sustained meeting: The surface transformation interplays with Tom and Bob's stepwise reconfigurations; (A) Tom and Bob reorganize for sharing the space around the desk. (B) They adjust the furniture for better viewing angles. (C) They reorganize to be able to collaborate closely and compare documents.

ment would provide more flexible choice and could potentially have an impact on the proxemic transitions in situations such as figure 2. Design of the transformations in shape-changing interfaces is often merely describing the start and end states of a shape change, but considering the entire trajectory might be crucial to its usefulness for supporting proxemic transitions.

Stepwise reconfiguration can be designed for in how the dynamic surface can transform in a coherent trajectory between a set of configurations. Prior work on comparing horizontal and vertical surfaces in relation to collaboration [28, 34] point toward how their respective properties support different activities. We explored the qualities of a surface that could shape into a wall and table display, while also providing opportunities for being a hybrid with a mix of vertical, horizontal or even 45-degree angles. We found during body storming with the first prototype iteration with two separate rotating table surfaces that – apart from the endpoints – the hybrid configuration of figure 10(B) provided a unique situation for collaboration. The below scenario illustrates how mixing vertical and horizontal surfaces might allow for physical transformations with multiple configurations along the trajectory between two endpoints, and the value of this is demonstrated through a scenario of stepwise reconfiguration (illustrated in figure 10).

> Tom wants to share an idea with Bob. He comes over to Bob's desk to quickly make sure that they align on the idea. Bob responds and Tom is about to return, but realizes he wants to show something else. The current

physical configuration allows for Bob to walk around on the side and bring his digital territory with him, allowing Tom's personal display area to expand (see figure 10(B)). This transition turns the display space into a shared space accommodating both group and personal display territories. Tom and Bob discuss and compare ideas at Bob's workspace for five minutes. They have reconfigured themselves in a face-to-face formation [18] with the shared vertical surface on their side and two personal territories on the horizontal surface with each their display area orienting towards themselves. As they reach common ground, Bob suggests that they spend a bit of time combining their work. At this point, they need a slightly different setup for more easily co-creting documents. They bring down the table to sit in a side-by-side arrangement [18] with a larger space for collaboration (see figure 10(C)).

What is to be noticed from the above scenario is how Tom and Bob initiate an informal meeting with a quick exchange, however, as it is sustained they gradually move toward a more tightly coupled collaboration by continually and gradually making proxemic transitions, i.e., either adapting their F-formations to the interface or reconfiguring it to shift the deixis and perceptual proxemics. It further illustrates the continuous negotiation of space as described in the empirical findings. By designing for meaningful steps between the endpoints, the presented scenario illustrates how dynamic furniture can facilitate the ad-hoc nature of informal meetings.

RADICAL SHIFTS

The final aspect of proxemic transitions that this paper brings forward is *radical shifts*. An important aspect of people's local mobility was their movements between different spaces to organize with the suitable F-formations and interaction proxemics to serve their particular purpose of collaboration and group size. As seen in table 1, informal meetings around workstations most often ranged from 2 to 5 participants. A snapshot from the field notes illustrates how groups would migrate their activity to an appropriate space when the current one is insufficient for the activity or group size.

> Three coworkers A, B, and C are organizing around a whiteboard. The whiteboard - because of its size and orientation on a wall - supports F-formations involving more than just two, where all can easily see the content, point to it, and switch between who has the pen to produce the content. Also people can easily switch between orienting towards the content and each other. At one point they have to discuss something that involves the digital content on A's machine. A and B move over to A's computer display to continue the discussion afterwards, while leaving C at his desk close to the whiteboard. A controls his computer, and B has visual access, but is only able to interact with the content through A, unless B takes over A's seat and control.

The whiteboard enables flexibility by its easy access and openness towards multiple people. As touched upon by Rogers et al. [34], wall displays are superior for changing group sizes

and presenting material, whereas tabletops support close collaboration at limited group sizes better. An advantage of large vertical surfaces is that people can organize in a semi-circular F-formation [18] around them with equal visual access and deixis abilities in relation to the content. When A and B leave C to look at A's computer, the current collaborative situation transitions into a new situation where A and B work closer together and C is left for personal work. If the meeting with C was intentionally concluded, everything is fine. However, the spatial circumstances are inflexible for sustaining the informal meeting in a group of three with simultaneous access to a shareable large surface and personal content from their workstations. It was rare that three people would organize around a display at a personal workstation due to the limited amount of space. Thus, the physical circumstances constrain the space of possible proxemic transitions for sustained informal meetings involving display content. One could hypothesise that the area does not provide the necessary physical space for enacting proxemics [17], and that this entails the group to make a radical shift of migrating the activity to a different space.

Radical Shifts with Dynamic Surfaces

We demonstrate how spatial adaptation is enabled by our dynamic surface to allow for adapting to a variety of group sizes and interaction proxemics. Careful attention is given towards the dynamics of *orientation* and *scale*. In related furniture-scale shape-changing interfaces there is usually either a focus on vertical dynamics as in the Shape-Shifting Wall Display [41] or horizontal dynamics as in TransformTable [40] or inForm [21]. What we found to be a significant aspect of knowledge sharing using displays is flexibility to reorganize for shifting the interaction proxemics involving a mixture of horizontal and vertical surfaces. The design of our dynamic surface builds on the findings in Rogers et al.'s comparison of vertical and horizontal displays [34]. Our findings indicated quick transitions between informal meetings that involved both cohesive collaboration and a variety of group sizes. The following scenario (see figure 11) demonstrates how a dynamic surface might accommodate for radical shifts in activity that involves reconfiguring the current location to allow for a larger group instead of migrating to another location.

> Tom and Bob are comparing diagrams (see figure 11(A)). Alice spontaneously joins the activity and stands at the end of the table. Together the participants arrange in a semi-circular formation [18] around the surface. Tom and Bob rotate one end of the surface to have a vertical display that they can all see fairly well. Alice can easily bring up her personal items on the dynamic surface using her mobile device, however, it is hard for her to gesture and point properly on the details of the vertical display. Tom transforms the surface into a board configuration (see figure 11(C-D)). This configuration allows for a semi-circular arrangement with all participants at an arm's length for controlling and pointing towards the display.

What is interesting in the above scenario is how shape change provides a new dynamic space for enacting territoriality [36] and proxemic zones [17] in collaborations. Scott et al.'s study three types of territories around tabletops; personal, storage,
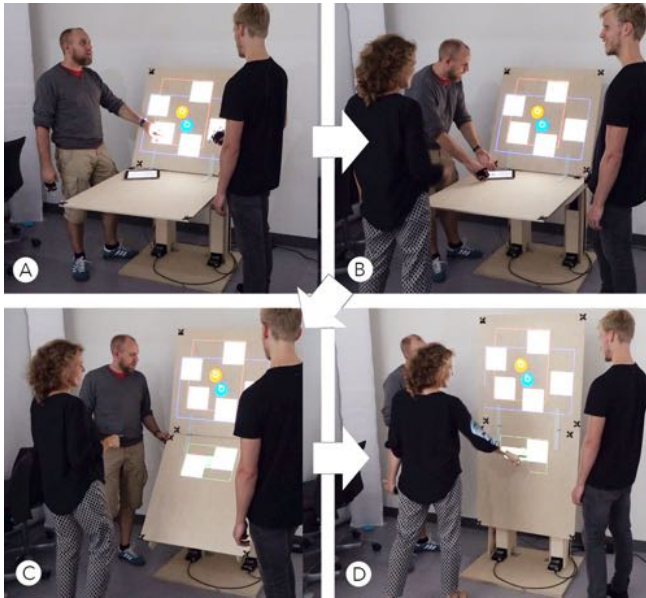
Figure 11. The workplace is spatially flexible and enables reconfigurations to accommodate various group sizes.

and group territories [36]. The above scenario illustrates how a shape-changing interface provides a new way of organizing territories on vertical and horizontal surfaces and how they can change the physical circumstances providing a different territoriality. Notice how Tom and Bob were able to conveniently share a storage space on the vertical surface because of its balanced orientation towards the two collaborators while having their respective personal zones. As Alice enters they change the configuration to enable Alice to become part of the group territory and give all equal access in terms of control, deixis and perception. This scenario is in line with the comparative study of [34]. Along with the design proposals of [41] and [40], our prototype provides further inspiration for envisioning how dynamic surfaces might enable more flexibility in facilitating shifting group sizes around content. The proxemic transitions with such surfaces might be as radical as moving to another work area with a whiteboard, in that you might have to move other physical artifacts such as paper or devices. However, in case the scenario would benefit from maintaining the same display environment, our prototype would provide a new way of conducting this collaboration.

DISCUSSION AND FUTURE WORK

The presented scenarios should be seen as abstract representations and initial explorations of the vision for how dynamic furniture can support the proxemic transitions in collaborative work. The prototype only touches upon a subset of the design space of proxemic transitions through its limited shape-changing abilities. It serves as a provisional artifact in designing for proxemic transitions, as well as articulating important qualities and challenges of dynamic surfaces for collaboration. There are obvious limitations to the form factor, limited interaction and transformations of the prototype, if envisioned as a traditional desk filled with paper, coffee cups, devices and decorations. In an office environment, it is much more likely that shape-changing surfaces will replace the surfaces that

are already serving as shared resources to groups of people. Further, combining the coarse-grained transformations of our dynamic surface with more fine-grained transformations like in [12, 21], would enable other physical artifacts to stay horizontal while the overall structure transforms. Along continued explorations of different purposes and shapes, the natural next step would be to further explore the interaction design for dynamic surfaces. Initial studies have been conducted in [41, 42, 40], however, more work on participatory design and user studies is needed for a better understanding of how interaction with dynamic surfaces should balance user and system control to be useful in a real-world context.

The design aspects of proxemic transitions are particular to the design space, in that it is unfolded in coupling empirically elicited scenarios in existing collaborative practice to potential future practices around dynamic surfaces. The notion of proxemic transitions and the aspects of speed, steps and radical shifts are important aspects that are particular to both human work practices and aspects of what shape-changing surfaces can accommodate for. These aspects of interactions are fundamental to human-computer interaction and have influenced previous work. Previous work has explored how technology might respond to how people move in and out of proximity [44, 14] and similar aspects in relation to interacting with single small-scale products [46]. With the introduction of proxemic transitions, we aim at capturing these aspects from a broader situational perspective, exemplified here with how collaborative work might unfold around a shape-changing surface. Introducing the dynamics of *collaborative work* within both shape-change and proxemic transitions allow us explore the intersection between dynamic work activities and reconfigurable physical spaces.

CONCLUSION

Learning from theories of proxemics and implications from empirical and design work, this paper has illustrated how shape-changing furniture can be meaningfully designed to support dynamics of collocated collaboration. Our research through design approach breaks new ground in the area of shape-changing interfaces by bridging empirical and constructive solutions within a real-world context, and our dynamic surface exploration provides complementary inspiration to the area of shape-changing furniture with its dynamic horizontal and vertical surfaces at furniture scale. It represents an initial investigation into the exciting area of shape-changing furniture by contributing with the perspective of proxemic transitions. In addition, scenarios with dynamic furniture serve to articulate the conceptual contribution of proxemic transitions as a characteristic of collaboration and as a design quality for dynamic surfaces. Three design aspects provide the designer with a sensibility towards specific aspects of how dynamic surfaces might support proxemic transitions, and thus provide a foundation for future design work.

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