An Empirical Study of how Socio-Spatial Formations are influenced by Interior Elements and Displays in an Office Context

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The design of a workplace can have a profound impact on the effectiveness of the workforce utilizing the space. When considering dynamic social activities in the flow of work, the constraints of the *static* elements of the interior reveals the adaptive behaviour of the occupants in trying to accommodate these constraints while performing their daily tasks. To better understand how workplace design shapes social interactions, we ran an empirical study in an office context over a two week period. We collected video from 24 cameras in a dozen space configurations totaling 1,920 hours of recorded activities. We utilized computer vision techniques, to produce skeletonized representations of the occupants, to assist in the annotation and data analysis process. We present our findings of socio-spatial formation patterns and the effects of furniture and interior elements on the observed behaviour of collaborators for both computer-supported work and for unmediated social interaction. Combining the observations with an interview of the occupants' reflections, we discuss dynamics of socio-spatial formations and how this knowledge can support social interactions in the domain of space design systems and interactive interiors.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**; **Empirical studies in collaborative and social computing**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: socio-spatial; office space; human-building Interaction; space occupancy

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1 INTRODUCTION

The built environment inherently shapes the social interactions we have with each other every day [33, 45, 51]. From schools to hospitals to cafés, certain types of social behaviours are encouraged while others are discouraged. Social norms dictate some of these interactions but others seem to emerge from interior elements in the space (e.g. furniture configurations, wall positions, computing devices) [22, 51]. For example, people gravitate towards seats which reduce the visual exposure of their computer screens [2]. When getting an opinion from a colleague on a document, sitting shoulder-to-shoulder, indicates a deeper level of collaboration and a longer time commitment than speaking face-to-face [33].

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In office contexts, it is becoming more important to understand the influence of the spatial aspects on social interactions and have the office design process explicitly support the desired interactions. The quality of social interactions have a profound impact on the effectiveness of the workforce [3, 12, 23]. Also, office layouts are becoming less standardized and are being more creatively designed, resulting in greater variations and diversity of designs [16]. An architect or designer may intend to support specific work styles and various collaboration spaces, but whether their design intent has the desired outcome is difficult to say yet.

Several theories rooted in social science describe spatial arrangements of people that can be used to analyze how people occupy space during social interactions. In *Proxemics* [22], four discrete interpersonal zones were introduced where people are most comfortable during different types of social interactions. The *F-formation framework* (or facing formation [27]) illustrates diverse formation shapes with social spacing and body orientations. However, these theories were focused on standing situations, especially for face-to-face interactions and is challenging to apply to office contexts. In recent offices, the ubiquitous use of mobile computing and wireless communication increases the *ecological flexibility* [35] in the office and allows social interactions to be more fluid and dynamic.

Therefore, the **objective** of our study is to understand *socio-spatial formations* in the office environment in relation to furniture configurations, interior elements, and the type of interactions (i.e. computer-supported and unmediated), as outlined in Figure 1. Socio-spatial formations are defined as the arrangements of people during social interactions including micro positioning of bodies, orientations, distances, and formation shapes (e.g. linear shape, L-shape). Using social trails as a metaphor, where similar ad hoc paths are formed by people repeatedly preferring to take a different route than where the sidewalks are placed, we aimed to explore how the findings on socio-spatial formations could inform future office interiors, similar to *learning by doing* practices [32] and *evidence-based design* approach [45].

To achieve these goals, we conducted a two-week ethnographic study using 24 cameras (Figure 1). Our camera setup covers a diverse set of space configurations including common and personal spaces, diverse desk sizes, desk arrangements, and interior elements. To preserve the privacy of occupants during the analysis, we converted the video into skeletonized representations using computer vision techniques, and developed a custom software tool (Skeletonographer) to play back and annotate the footage.

We first analyzed the skeleton data using thematic analysis [21] and found all the formation shapes that occurred in the office. Inspired by Lawson [33] and Kendon[27], we then defined a socio-spatial framework that includes ten formation shapes and three desk-relative arrangements.

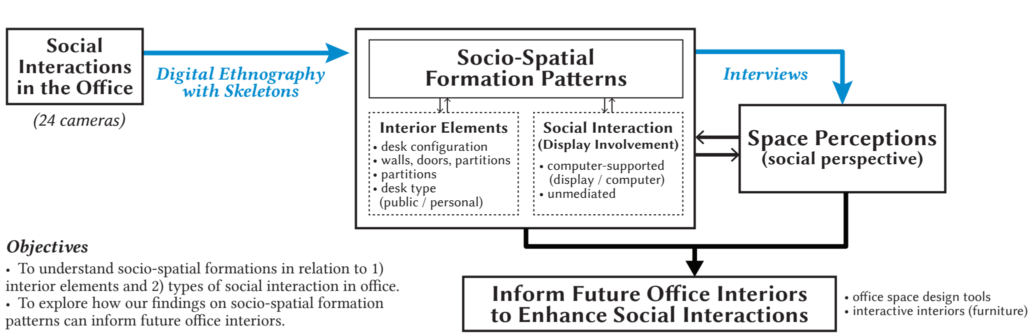

Fig. 1. Objectives and overview of our study.

Using that as our analytical lens, we re-analyzed the data by annotating with our framework and found socio-spatial patterns in relation to the interior setup and interaction type. Occupants were interviewed and asked to reflect on their behaviours and we corresponded their answers to observed formation patterns to understand space perceptions that cause certain patterns.

Our study provides three contributions to the human-computer interaction (HCI) and computer-supported cooperative work and social computing (CSCW) community: 1) We revealed socio-spatial formation patterns in relation to *interior elements* and *types of social interactions* with corresponding occupants' space perceptions. In addition to static formation patterns, we also reported patterns in formation transitions. 2) We proposed a dynamic concept of socio-spatial formations and discussed how this knowledge can support social interactions in the domain of space design systems and interactive interiors. 3) We proposed a computer-vision based ethnographic method which is applicable for other field studies using anonymized skeletons.

2 RELATED WORK

Our research bridges existing work on *socio-spatial theories* and *space-relevant human behaviours*. We reviewed the related work in the following four topics: 1) theories behind socio-spatial formations, 2) the influence of physical office spaces on social behaviours, 3) techniques for shaping physical office spaces that facilitate social interaction, and 4) pervasive sensing to understand occupant behaviours in spaces.

2.1 Theories Behind Socio-Spatial Formations

There have been several efforts in HCI and CSCW to understand spatial patterns during social interactions in the physical space with the goal of informing interactions for ubiquitous environments. One schematic framework is *Proxemics* which was coined by Edward Hall [22] to illustrate spatial relationships (distances) in everyday social interactions. He proposed four discrete interpersonal distances found in American culture: the *intimate* zone (0–0.45 m), the *personal* zone (0.45–1.22 m), the *social* zone (1.22–3.66 m), and the *public* zone (>3.66 m). This contributed to *proxemic interactions* [9, 19, 61] that use spatial distances as an input; however, the system is somewhat abstract, only considering point-to-point distances and standing interactions. Inspired by Sommer [52] who looked into spatial arrangement as a function of group tasks, social relationships,and individual's personalities, we build upon proxemics theory by considering the diverse spatial constraints imposed by the physical interiors, sitting and standing states of occupants, and collaborative situations where people do not necessarily face each other.

Similarly, *F-formations* were proposed by Adam Kendon [27] to illustrate spatial formations with social spacing and orientation. The framework decomposes a socio-spatial arrangement into an *o-space* and a *p-space*. *o-space* is the convex, empty space surrounded by the people involved in a social interaction, whereas *p-space* is the space that contains the bodies of the people involved in the interaction. In HCI, F-formations contributed to the domain of human-robot interactions [25, 30], multi-device interactions (e.g. kiosks and tabletop displays) [36, 37, 55, 57], and technologies embedded in physical environments (e.g. in the kitchen, cubicle walls or information centres) [15, 37, 43]. We applied this framework to Human Building Interactions (HBI) and utilized *F-formations* as our analytical lens to evaluate how people occupy spaces in a given office setup during social interactions.

Beyond the two major theories mentioned, some researchers have tried to analyze people's micro-behaviours (e.g. formation transitions, body gestures, poses and actions) in the physical environment. Shapiro et al. proposed *interaction geography* [50] to map visitors' movements and social activities on a museum floor plan to understand socio-technical practices in museums. Krogh et al. [29] introduced three concepts of socio-spatial literacy : *proxemic malleability*, *proxemic* *threshold*, and *proxemic gravity* to describe space-dependent behaviours such as "pointing at a display" or "rolling their chairs to re-orient themselves". Motivated by these works, we explored how interior elements including various sized desks, types of desks, walls, partitions and desk arrangements can influence the occupant's formations and poses. We denote these interactions as socio-spatial formations.

2.2 Understanding the Influence of Physical Office Spaces on Social Interactions

For decades, researchers from multiple disciplines such as architecture, sociology, psychology, and environmental behaviour have attempted to understand how the design, layout and interior of physical spaces affect human behaviour [4, 22, 49, 51]. Sommer [51], the pioneer of social design in the field of environment behavior psychology, argued that minor adjustments in furniture arrangements could induce alternative social behaviours. For example, chairs arranged into small groups around tables could encourage more active interactions. Specifically in office contexts, the mainstream approach in the late nineties was to investigate the influence of physical environments on communications [3, 11, 12] and productivity [23]. For example, levels of communication and creativity increased after occupants moved from an enclosed layout to an open layout [3, 12]. Still, the scientific rigor of these findings has been challenged due to scattered empirical evidence [18, 47].

Recently, studies inspired from the tradition of *space syntax* [24] have looked deeper into the relationship between office spatial layouts and social interactions [46] in architecture and HCI. Researchers found that social interactions were predominant in printing rooms and kitchens [13, 17] as well as in workstation areas [44, 46]. However, most of them have focused on statistical analysis using only the frequency of interactions as the independent variable.

In this paper, we extend the works above by looking at social interactions from a micro-perspective, looking at how physical interior elements influence socio-spatial formations, arrangements, and poses, instead of measuring the frequency of interactions. We argue that this approach is significant for informing office space design where furniture and architectural layouts act as behavioural constraints. Only a few works in HCI and social behavior study the relationship between social formations and physical environments, including a tourist information centre [37], table shapes [56], display angles in a museum [26], and seated positions near common desks [33, 51]. We build upon these approaches in office environments with more varied devices, interior elements, and different types of desk configurations.

2.3 Towards Physical Office Spaces that Facilitate Social Interaction

Several attempts rooted in HCI have been made to plan *physical* office spaces that enhance work experiences in terms of space analysis [2, 40] and interactive systems [8, 15, 53, 63].

2.3.1 Space Analysis. To analyze the physical characteristics of a space, *space syntax* [24] has been proposed to quantitatively analyze spatial formations and their impacts on human experiences in architectural studies. A popular example is the *visibility graph* [58], which visualizes the mutually visible locations in a spatial layout. Extending that concept, Nagy et al. [40] evaluated *social congestion* using space topology. However, there is room for improvement to simulate more realistic social interactions in a given interior setup.

Therefore, we extend the work of Backhouse et al [7] who used an ethnographic approach to understand natural social interactions in the office and observed social formation patterns in-the-wild. Building upon the approach of *data-driven design* [45, 48], our encompassing goal is to argue for the inclusion of occupants' space usage behaviours in space design and analysis.

2.3.2 Interactive Interiors for Social Interaction. Several interactive techniques for robotic furniture have been proposed to enhance work experience by overcoming spatial constraints in HCI. The

Fig. 2. Office space used in our study.

majority of them focused on single-person usage scenarios. Bailly et al. [8] introduced an actuated monitor, a mouse and a keyboard that adapts to the user's behaviour, while Wu et al. [63] proposed the concept of an responsive monitor that helps users maintain ergonomic poses. A similar approach was applied to desks or tables; for example, a desk that shape-shifts to support user's work preferences [60], and automatic height-changing desks [34]. Moreover, robotic furniture that moves around the space based on human behaviour has also been demonstrated [42, 54].

Few works convey social interaction scenarios for interactive interior elements. Takeuchi et al. [53] introduced the concept of a *weightless wall* that blocks sound using headphones and Danninger et al. [15] proposed the cubicle partition that changes it's transparency, both works based on the body orientations of the parties involved. Shape-changing desks were recently introduced to manage the notions of *interaction proxemics* in medical consultations [56] and informal meetings [20]. This work is highly motivational for our research, and we contribute by investigating how socio-spatial behaviours including poses and formations should inform interior elements to enhance collaborative experiences.

2.4 Pervasive Sensing to Understand Occupant Behaviours in Spaces

To understand how environmental resources impact people's experiences, the notion of *pervasive sensing* has been introduced, which is a technique that continuously observes individuals and their interactions. Several researchers leverage a combination of a pervasive sensing systems to analyze space-use behaviours using ambient and wearable devices such as blob sensors with Bluetooth wrist-bands [5, 59], RFID badges [13], tracking tags & Zigbees [62] or infrared sensors for indoor localization [2]. These techniques are useful for collecting data anonymously; however, these do not convey details of occupant behaviours. Therefore, we extended the traditional ethnographic study with anonymous pervasive sensing by utilizing computer vision techniques to produce skeletonized representations of the occupants.

3 METHOD

To understand how interior elements and desk configurations influence the social formations in the office, we conducted observations of occupant poses and spatial arrangements in physical spaces. Our experimental setup consisted of 24 cameras installed at pre-selected locations as seen

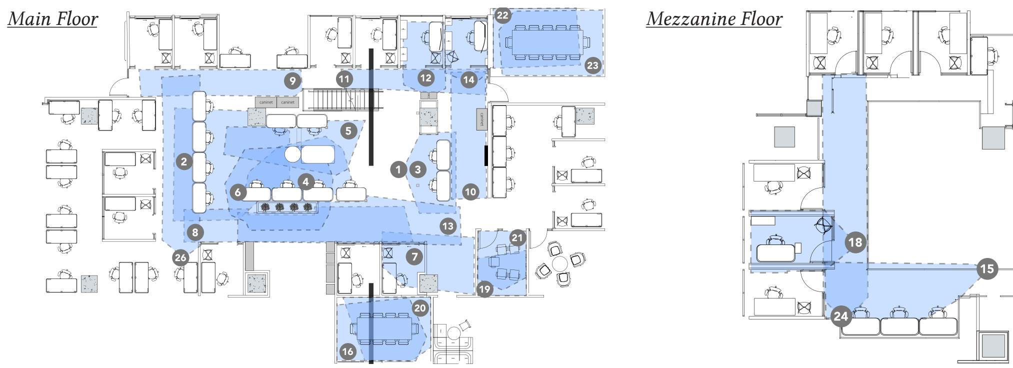

Fig. 3. Office layout used in the study. Grey circles indicate camera positions, and blue regions indicate camera coverage.

in Figure 3. We built upon traditional *digital ethnography* [31] by using skeletons of individuals rather than using raw video data. The skeletons were generated using computer vision through the OpenPose library [14], capturing features as connected vertices corresponding to features on the human body as seen in Figure 5. We explored this approach in an effort to improve privacy, especially when dealing with the public. To make observations and annotate the skeletons, we implemented a custom video tool (Figure 6). As a result, our study demonstrates that ethnographic studies using skeleton data have potential for future in-situ social studies.

3.1 The Office

Our study area (Figure 2) was a section of an office occupied by the research division of a global software company located in North America with a relatively flat hierarchy working culture. The study area had 60 employees from multicultural backgrounds and countries including Canada, US, France and Korea. The organization was structured into three research groups, and collaborations within groups were usually for work updates, brainstorming, discussing issues, and information sharing. However, informal social interactions occurred frequently between groups as well.

The study area was 102 ft x 70 ft and composed of a main floor and mezzanine with various areas, including: private workspaces (cabins), open office areas, meeting rooms, and corridors as shown in Figure 3. All the employees had height-adjustable desks with articulating monitor arms for a partially customizable work environment. The devices people used varied from multiple desktop workstations to a single laptop.

3.2 Space Configurations

From our informal observations prior to the official study period, we observed that social interactions in the office often occurred near desks accompanied with papers, displays and/or laptops. The *common desk* areas (i.e. meeting rooms) were utilized for long-term collaboration, while *personal desk* areas were more commonly turned into temporary social spaces by visits from co-workers.

Our observations covered both common desk areas and personal desk areas, and we assumed that different space-usage interactions could exist between them. We also covered various *interior elements* including partitions, walls, configurations and various desk sizes as shown in Figure 4. Common desks were mostly located with a fixed large display at one end of the desk and were in meeting room spaces surrounded by four walls. We selected three common desk areas with different desk sizes (Figure 4-top) for our study. All personal desks were the same size, therefore,

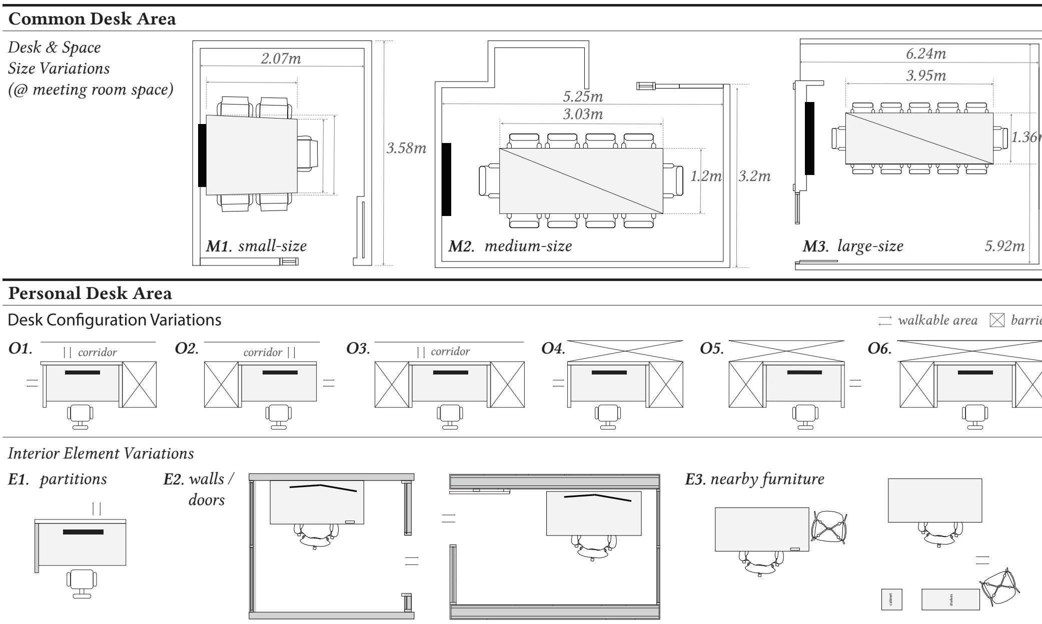

Fig. 4. Desk Configurations in our study.

configuration was a more significant aspect affecting behaviour. We selected six different personal desk configurations in the open office (Figure 4-middle), based on whether there were barriers next to or behind the desks. Some personal desks were surrounded by walls and doors, supporting a more private working space, others with only a partition (Figure 4-bottom).

Our goal for this study was to obtain a general understanding of how different types of spatial features affect *space-use behaviours* in terms of social interaction. Instead of preparing controlled spatial features for lab studies, we instead chose *in-the-wild* field studies with various setups.

3.3 Data Collection & Technical Setup

3.3.1 Camera Setup. Our setup consisted of 15 Raspberry Pi 3 A+ and 9 Raspberry Pi B+ single-board computers, each equipped with Raspberry Pi Camera modules (Version 2). The cameras were chosen for their inexpensive cost, built-in Wi-Fi capabilities and the ability to fully program and customize all software, allowing us to implement algorithms such as motion compression. Each unit was powered by a standard USB power supply. Cameras were mounted throughout the office with adjustable mounting hardware.

3.3.2 Camera Location Planning & Installation . While planning the camera positions for coverage of the 17 desk areas, several issues needed to be considered. First, it was difficult to find camera positions for obtaining full body coverage due to furniture occluding views within the office, an important requirement of our computer vision system. To minimize occlusion, we typically employed at least two cameras to capture the same location from different angles. Second, in order to minimize the amount of video data and reduce subsequent processing and analysis time, we wanted to find camera positions that could cover multiple target areas. Third, installation elements (e.g. mounts and power supplies) had to be taken into account during planning.

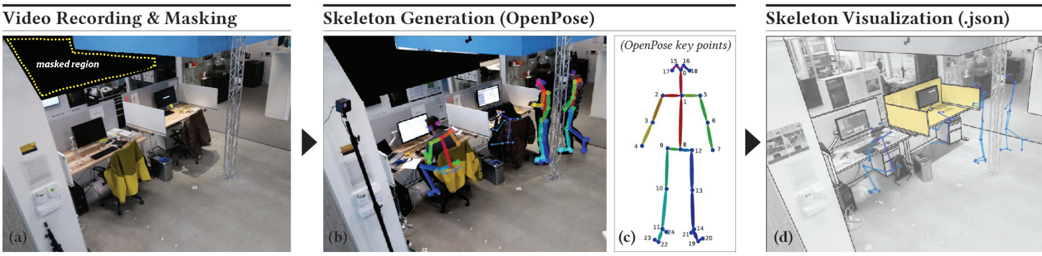

Fig. 5. Data Processing

To do this, we used Autodesk Revit to simulate the camera coverage within a real-scale 3D architectural model. We prepared custom camera families in Revit that matched the specifications of our Raspberry Pi camera modules (i.e. focal length and field of view) so that we could accurately plan the camera coverage and power supply requirements. In total, 24 cameras were used in this study, the final camera positions shown as grey circles in Figure 3. We then installed the cameras in the physical space based on our Revit model.

3.3.3 Recording & Motion Compression. We captured video of social behaviours at 17 desk locations for two weeks (10 working days) from 9:00 am to 5:00 pm local time. All video footage was saved in a secured Amazon S3 bucket and used as input to generate anonymized skeletons. To reduce storage and post-processing requirements, we developed a simple form of motion compression to only store video for motion based events. We perform this compression in-memory on the raspberry pi using a circular buffer. Once every second, frames are compared for color based changes within the scene. If a significant change is detected, the contents of the circular buffer are written out to file, and a subsequent video is saved containing the motion footage. This is repeated until no more significant motion is detected.

3.3.4 Masking & Skeleton Generation. To keep costs fixed and reuse existing hardware, we used 3 local workstations with NVIDIA Quadro P6000 graphics cards. One of the workstations was also used as a local file server for the raw video and processed outputs. We decomposed processing of files into tasks and developed a job management script in Python to distribute them as jobs. Synchronization was performed using Amazon's Simple Queue Service (SQS). During processing, each workstation retrieves a video from the file server, performs masking and *OpenPose* [14] processing, then finally stores the results back onto the file server.

Masking is performed to remove areas where additional privacy is required: monitors, collateral occupants outside of the area of focus, or people who opted out of the study. Masking is achieved by applying an overlay mask image over raw video footage using the FFmpeg application as shown in Figure 5-a. Afterwards, the *OpenPose* library can recognize the occupants' embodied poses from the masked videos and estimates skeletons based on 25 key points (Figure 5-b, c). JSON files corresponding to each frame in the video are generated, containing key points for each of the occupants in the video.

3.4 Skeletonographer: Skeleton-based Digital Ethnography Tool

To analyze the skeleton data, we implemented a custom playback tool, *Skeletonographer*, for three reasons (Figure 6). First, we needed a tool that would be able to *play back* the frame-by-frame skeletonized data, providing similar *affordances* to standard video playback tools which are often used in traditional digital ethnographic studies. Second, to understand socio-spatial patterns at

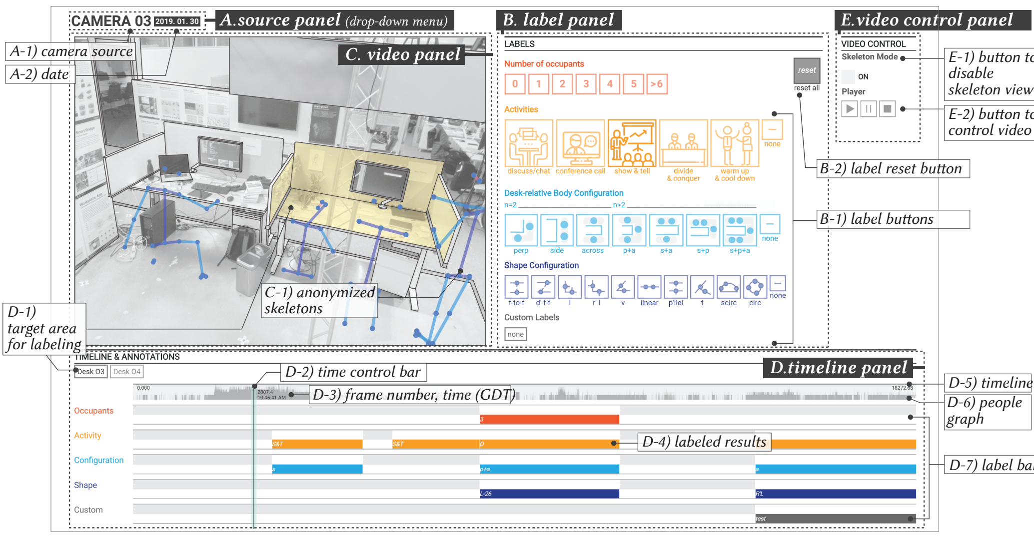

Fig. 6. The interface of our annotation tool, Skeletonographer.

different space configurations, we needed a tool to annotate and classify occupant's skeletons space by space using custom labels obtained through the initial analysis process to find further patterns. Third, we needed to efficiently manage a large amount of data that was collected for 1,920 hours from 24 locations. We used a custom *Node.js* server to serve the web-based playback tool as well as a concatenated version of the selected skeleton data set. The tool was written in JavaScript and HTML, with the skeleton data being drawn onto a canvas element on the page.

The *Skeletonographer* tool is composed of five parts: a) source panel, b) video panel, c) video control panel, d) labeling panel, and e) timeline panel as shown in Figure 6. The ***source panel*** enables users to select data using the camera number and the date through a drop-down menu bar. The ***video panel*** displays skeletons from a selected source on a still photo similar to traditional video players using the absolute timeline. Users can move through time by scrubbing the *time control bar*(Figure 6, D-2) on the ***timeline panel***. The absolute time of a specific moment is displayed next to the time control bar.

Additionally, the ***labeling panel*** was implemented for further analysis processing. We added labels for activities, number of people in the interaction, and socio-spatial patterns as icons (Figure 6, B-1). To annotate the skeleton data, users need to first clarify the specific area for the analysis using the pre-defined buttons (Figure 6, D-1), then the video will highlight the selected area in yellow. Users can annotate behaviours by clicking the labels. They can also create new labels if needed using a keyboard shortcut. The annotated results are shown on the *timeline panel* to keep track of annotations. The results are synchronized between cameras to support cases where the same area is captured from multiple cameras. Once users have finished annotating a data set, they can export the data as a JSON file with time-stamped data for each label. This file can be used for further analysis, processing and storage.

The video properties can be updated from the ***video control panel***. We implemented a toggle button that can reveal the original video for cases where skeletons we incorrectly generated for any of the available views. In addition, users can play back the skeletons similar to video players using buttons or keyboard shortcuts.

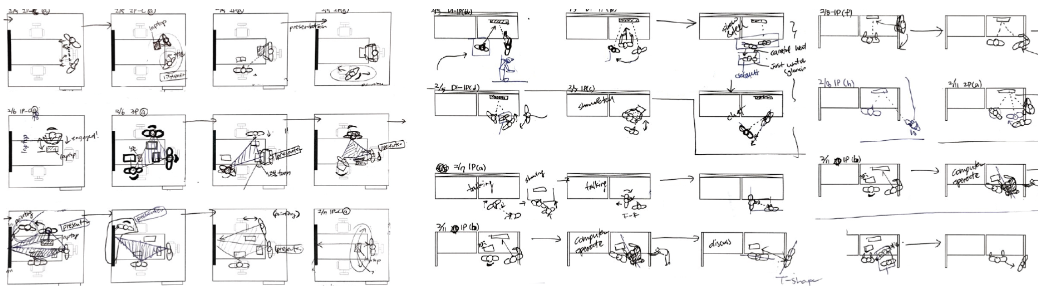

Fig. 7. Example of our video transcription results.

3.5 Data Analysis

The collected data was analyzed using thematic analysis [21] to understand the overview of socio-spatial formations in the office. As a first step, we used *Skeletonographer* as a video playback tool and watched seven days worth of data similar to traditional digital ethnographic studies. We transcribed the skeletonized videos by sketching occupants' spatial arrangements using similar notations as Krogh et al. [29] and Paay et al. [43]. We sketched the head and body orientation, estimated gaze direction, poses, and added additional comments to describe the situation (Figure 7). When there were any changes in formation, they were captured using illustrations of path movements or drawing sequences.

As a second step, we annotated all the collected skeletonized social interaction data using *Skeletonographer*. The labels were derived from the previous step, including the desk-relevant body arrangements (e.g. "across", "adjacent"), formation shapes (e.g. "face-to-face", "T-shape"), the number of occupants, types of social activities (e.g. "show & tell", "discuss", "conference call"), and sitting or standing status. Custom labels were created when we discovered new patterns, for example, poses such as "leaning on desk" or "pointing".

We then revisited all our annotated skeleton data and transcriptions to analyze socio-spatial formation patterns. Annotated skeleton information was useful in filtering and finding recurring patterns of formations and activities (e.g. two-people, unmediated discussions) in different space configurations. Transcribed images were useful when checking formation transitions throughout the interactions.

Finally, we conducted one-on-one interviews with twelve employees to understand the perceptions behind the observed socio-spatial formation patterns. As the collected data was formed as anonymous skeletons, it was difficult to ask about formations that each participant exhibited. Instead, we prepared sample sets of skeletonized videos for each pattern. We showed the videos, described the pattern, and asked for their opinions, perceptions, and contextual details for each formation pattern. Some participants noticed themselves from the skeletonized representations, reflected on their experience, and described that situation (e.g. the type of social interaction it was, what encouraged them to exhibit that specific formation, how environmental aspects affected their social formation). When they did not recognize themselves, they tried to recall previous experiences and shared their thoughts.

3.6 Research Ethics for Installing Cameras in Public Space

As a company, we consulted guidelines and rules for overt video surveillance in the private sector as outlined by the Government of Canada [41]. In addition to the guidelines, four independent groups were consulted. First, *corporate legal counsel* performed an overview of legislation and best practices as well as employee rights and safety, including General Data Protection Regulation (GDPR) concerns. Also, the *internal security team* which oversees all systems containing private data performed an investigation on behalf of the *facilities management team* who also conducted their own review. Finally, the *management of the employees* in the affected areas were consulted and interviewed, where comments and concerns were addressed and accounted for in the final design of the study, including collection systems, notices and information presented to employees.

An internal informational *website* was created to provide the basic overview of our project and let occupants access information about the camera setup. The site also contained information on our project background, goals, camera installation plans, data storage methods and the precautions employed to protect privacy. Access to the website was restricted to users located within the company firewall only. Then, *two presentations* were made, one to the managers and team leads of the space and a subsequent meeting for all the employees in the space. The presentations focused on explaining the intentions, goals and details of the data collection. We shared which areas would be covered by cameras, and highlighted the use of skeletonized human figures unless there was ambiguity. Following the presentation, we had a 40 minute open discussion with occupants to address concerns and discuss possible solutions and requested permission for the study. Then, we created *surveillance notices* and posted them in each of the areas covered by the cameras. The signage provided information about recording period, the actual camera position, what each camera would see (Figure 5-a), what the researcher would see (Figure 5-d), and a link to the website. This was done not only for the occupants, but also for visitors entering the space.

4 SOCIO-SPATIAL FORMATION FRAMEWORK FOR OFFICE SPACES

We build upon Adam Kendon's *F-formation* framework [27] to use as our conceptual lens in analyzing how social formations differ in diverse office configurations. Previous work using F-formations [37, 43, 57] are limited in three ways. First, they focused on standing social interactions when office collaboration frequently includes combinations of sitting and standing which can evoke different aspects of social proximity and formations. Second, social interactions in the office are often a combination of dynamic activities, such as *discussing*, *presenting*, and *co-creating*. During these activities, occupants are not necessarily looking at each other. Third, the majority of social interactions in the office occur in the proximity of spatial elements that influence their social arrangements.

To analyze office social formation patterns, we define two new classifications: *formation shapes* and *desk relative arrangement*. *Formation shapes* illustrate the geometric shapes of formations. Additionally, inspired by the work of Lawson[33] and Sommer [51], who looked into chair positions occupied near a desk, we also considered *desk-relative arrangement* as an additional layer of framework.

4.1 Formation Shapes

Our analysis generated 133 video transcriptions for common desks and 282 for personal desks. The analyzed shapes of the social geometry are based on the people's relative position and body orientation. We observed five of Kendon's known formations (i.e. *Vis-à-Vis*, *side-by-side*, *L-shape*, *Semi-circular*, *Circular*) and two of Paay's additional formations, which were observed in social cooking scenarios (i.e. *V-shape* and *Reversed L-shape*). Additionally, we we found 104 video transcriptions (Figure 7) that did not fit into formation shapes, and identified three new formations not previously illustrated in other studies. We named these new formations: *Parallel*, *T-shape*, and *Z-shape*.

Although Kendon's basic formations [27] were derived from standing social interactions, those were also observed in our studies of mixed sitting and standing situations. The *Vis-à-Vis (face-to-face)* formation occurs when people are opposite and facing each other, sharing a transactional

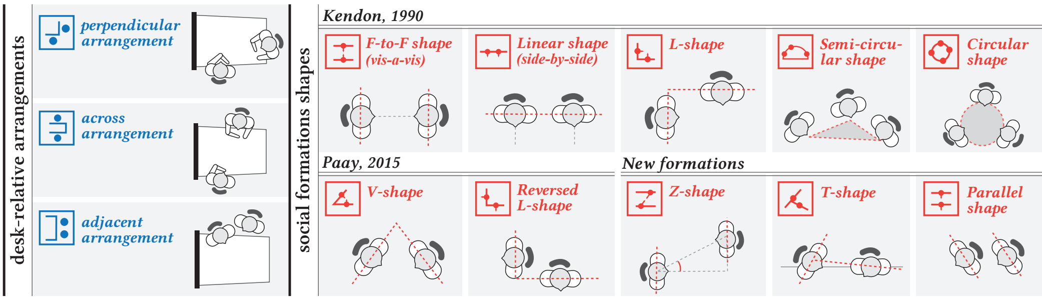

Fig. 8. Framework used to analyze socio-spatial formations in the office.

space between them. This formation was frequently observed when people were sitting across the desk or standing behind the chair clearance space. The *Side-by-side* formation is defined as standing next to each other, abreast. This formation was shown while working on concurrent but independent tasks or when demonstrating work. The *L-shape* formation represents people standing orthogonally to each other and facing a shared transactional space in front of them. This was mostly shown while having a brief chat or performing separate tasks while collaborating in the office. When there are more than two people, *Semi-circular* formations were dominant when engaged in a shared visual focus such as a TV or computer. Similarly, *Circular* formations were dominant for long-term discussions, although the shape of the circle depended on the physical environments.

We also observed two additional formations that were identified in kitchen collaborations [43]: the *V-shape* and the *Reversed L-shape*. The *V-shape* formation has people facing forward similar to the side-by-side formation but their bodies are slightly tilted to face each other. In the kitchen, this shape was shown when people were conversing while being actively engaged with individual tasks. However, in the office, this formation was more frequent when they were engaged in discussion near the desk they were sitting at. The *Reversed L-shape* formation is denoted when bodies were in an L-shape configuration but facing away from each other. Unlike the Reversed L-shape in the kitchen, which was formed when cooks were working at different cooking benches, in meeting rooms, people construct this shape while giving presentations on the public display.

Beyond these shapes, we found three new spatial arrangements that are applicable to social interactions in the office: the *Z-shape*, the *Parallel* formation and the *T-shape*. The *Z-shape* is formed by people facing each other but not within the same line. This is different from how Paay [43] defined *Z-shape*; which is side by side but facing opposite directions. In the office environment, people often formed a *Z-shape* instead of a face-to-face shape even though there was enough space. A *Parallel* formation is where people are not in the same line, but orienting their bodies towards the same direction. *Parallel* formations seldom happen in ordinary social contexts, but were frequently seen when a single person shares their work using a computer while sitting, with the other person listening while standing. The *T-shape* formation occurs when people's bodies are in the same line, with only one person's body oriented towards the other's. This arrangement is also rare but frequently observed during discussions near the desk area.

4.2 Desk-Relative Arrangements

In addition to formation shapes, we added an additional layer to our framework, the *desk-relative arrangement*. We observed that the majority of social interactions occur near the desk, and how people locate themselves around the desk at each configuration leads to different space-usage patterns and social behaviours. Therefore, we set three different arrangement types using the occupants' position as shown in the left of Figure 8. First is the *Perpendicular* arrangement where people locate themselves on two orthogonal sides near the corner of the desk. The *Across* arrangement is where people are located across the desk using the desktop as a transactional space, while the *Adjacent* arrangement is where people are located on the same side of the table. When there are more than two people in social interactions, those can be explained by decomposing them into multiple base arrangements.

The desk-relative arrangements do not stand for any social shapes. For example, *perpendicular* arrangement does not connote *L-shape*; people can form *face-to-face* or *V-shape* formations by freely moving around the space while maintaining perpendicular positions. Therefore, we combine these two classifications to explicitly illustrate the socio-spatial behaviours in the office spaces.

5 FINDINGS 1: STATIC SOCIO-SPATIAL PATTERNS IN THE OFFICE

In the following section, we describe observed static socio-spatial patterns in relation to the *type of social interaction activities* (i.e. unmediated interactions & computer-supported interactions), and *the type of office space* (i.e. common space & personal space) as shown in Table 1. For each finding, we further describe the aspects that influence the observed patterns by aligning them with results from the interview.

(calculated based on Σ time)	Common Desk Area	Personal Desk Area
Unmediated	66.23%	42.97%
Computer-supported	33.77%	57.03%
Total Social Interactions	100%	100%

Table 1. Frequency of unmediated and computer-mediated social interactions for each desk type. The calculation is based on the total duration of instances that are annotated as each combination.

5.1 Unmediated Social Interactions

In this study, we regarded *unmediated* social interaction as interactions without the involvement of computing devices. The results showed that 66.23% of social interactions in common spaces and 42.97% of social interactions in personal spaces were unmediated social interactions (Table 1). Compared to computer-supported interactions, *interior elements* were found to have a bigger influence on static socio-spatial formation patterns as shown in Figure 9.

5.1.1 Common Desk Areas. Unlike when people occupied common desks for individual work [2], our study showed that people occupied the areas closest to the door without concern of *visual exposure* of their laptop display. In addition, different from the study that observed standing occupants in public vacant spaces [27], we found that in sitting situations, socio-spatial formations are influenced by *desk size* and the position of surrounding *walls*.

Influence of desk size. *Adjacent* arrangements were dominant at M3 (56%) compared to M1 (21.05%) or M2 (37.5%) as shown in Figure 9. The interview revealed that the *size* of the desk influenced this formation pattern. The participants highlighted that the *depth* of the desk at M1, which is 1.3 m, was considered too deep to employ discussions effectively, especially when there were only two people. However, *adjacent* arrangements caused ergonomic difficulties during the

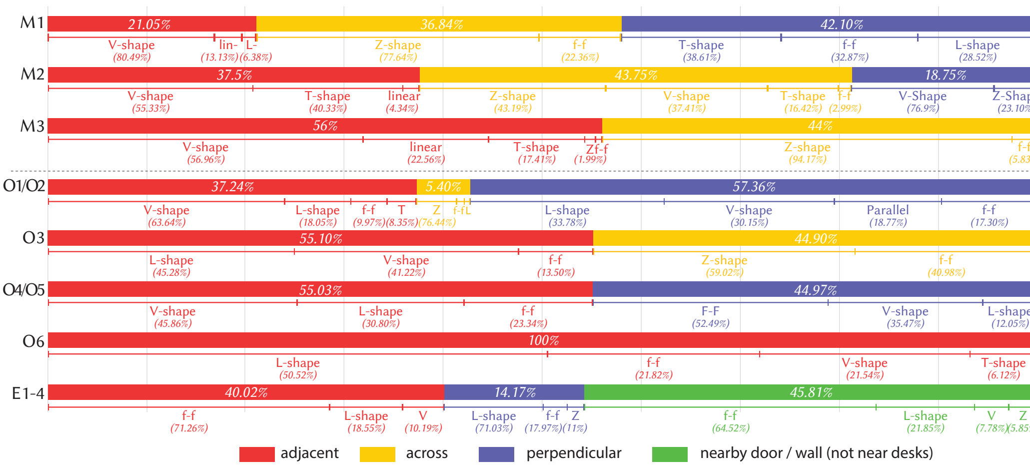

Fig. 9. The frequency of desk-relative arrangements for each spatial configuration during unmediated social interactions are illustrated as bars. The frequency of formation shapes for each desk-relative arrangement are illustrated as lines underneath their corresponding bars. The frequency was calculated based on the total duration observed.

discussion. Therefore, they moved backwards and oriented their bodies towards each other to form either *face-to-face* (Figure 10-b,c,f) or *V-shapes* (Figure 10-a). The space farther away from the desk was actively occupied.

Influence of walls. People at M1 did not initially arrange themselves into *adjacent* setups, even though the length of the desk was long enough to accommodate two people (Table 1). All the *adjacent* arrangements observed at M1 were instances following computer-mediated interactions. Interviewees mentioned that the *walls* located <1 m from the desk made them feel socially uncomfortable with sitting next to each other, and locating at different sides of the desk was found to be the solution to overcome this (Figure 10-g,h). This leads to a high frequency of *perpendicular* or *across* arrangements as shown in Figure 10-g-l.

Influence of a table between people. The *across* arrangement was a common formation for all common desk areas (Table 1-*yellow*), and having a desk between the occupants demonstrated different social behaviours. In contrast to *perpendicular* and *adjacent* arrangements where occupants tended to stay close, people arranged *across* from each other often kept a larger distance with less frequent eye contact. For example, they located diagonally instead of taking directly opposite positions, and rotated their bodies or heads as a *Z-shape* (Figure 10-k). One instance showed that people stretched their legs parallel to the desk and formed *T-shapes* or *L-shapes* (Figure 10-j).

5.1.2 Personal Desk Areas. All the occupants in the office have their own personal desks, and they casually visit other's desks for informal discussions. As soon as the *owners* of the personal desk noticed they had a *visitor*, they turned their head and started a conversation. If the discussion continued for more than about one minute, both *owners* and *visitors* changed the position or rotation of their bodies. The *desk arrangements*, *desk partitions* and *sit/stand status* was found to have an influence on their socio-spatial formations.

Influence of desk layout. For all types of personal desk configurations (Figure 4 O1-O6, E), the *adjacent* arrangement with *L-shape*, *V-shape* and *face-to-face* formations were frequently seen during unmediated social interactions (Figure 10-u-x). Compared to common desk spaces, they

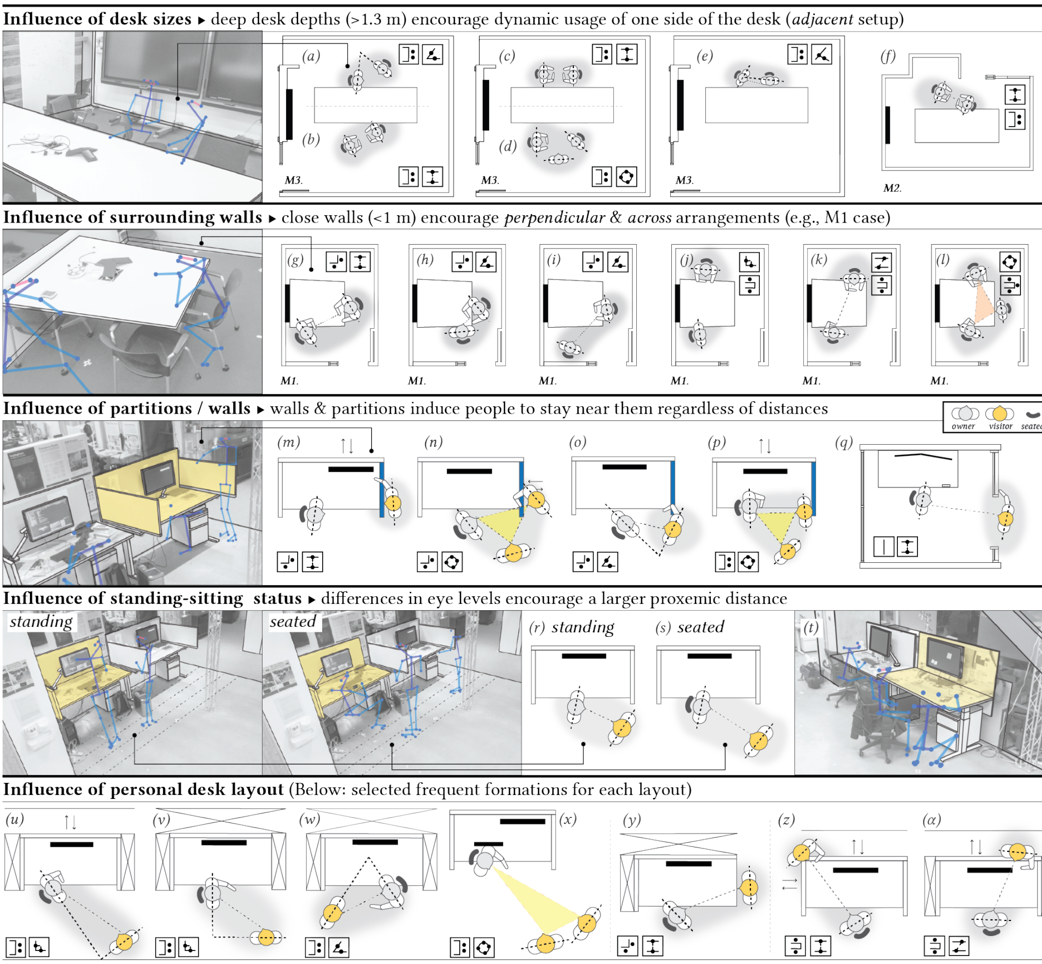

Fig. 10. Frequently observed socio-spatial formations during unmediated interactions. Examples are categorized based on spatial influence.

maintained a farther social distance and occupied a relatively larger space. The interviews revealed that people regard personal desks areas as private spaces, and tried to find a location that does not invade privacy but is reasonable enough to have a conversation. Their overlapping transactional area was usually the space behind the desk, which sometimes generated an upside down *V-shape* (Figure 10-w).

Variations were shown when any edge of the personal desks was open. For the desks with open sides, about half of the unmediated interactions occurred in *perpendicular* arrangements (Figure 9 O1/O2, O4/O5). The shape varies among *V-shape*, *L-shape*, and *face-to-face*, depending on the length of their discussion. When the back of the desk is approachable, about 45% of visitors formed *across* arrangements during unmediated interactions (Figure 9-O3) with *Z-shape* (Figure 10-α) or *face-to-face* shapes (Figure 10-z). Interviewees mentioned that they prefer these formations from the perspective of both *visitor* and *desk owner*, as their display is not visually exposed.

Influence of partitions. Partitions (30 cm tall) or architectural features near desks were found to contribute to certain social formations. *Visitors* tended to stay near partitions to lean on them (Figure 10 m,o,p). One person even grabbed and leaned on the metal truss near a desk. Interviews revealed that interior elements near personal desks that can be leaned on (e.g. partitions or columns) provided additional comfort when in someone's personal area regardless of social distance. Interviewees mentioned that these interior items acted like a *security blanket*, allowing comfortable interactions even when there is limited space.

Influence of doors. When there were doors or walls near personal desks that physically divide the personal space from corridors (Figure 4 E2), *visitors* frequently stood near the wall or door (Figure 10-q) for short-term discussions. Interviews showed that they preferred to stay near these physical divisions for short discussions (e.g. asking for advice or asking simple questions), as standing on the boundary of personal and common space can provide an impression that the conversation will not take long.

Influence of standing or sitting status. Figure 10-r and s illustrate two example cases, one with a seated *owner* and the other with a standing *owner*, both influencing the social proxemic distance. The distance between people were closer when they were both standing and maintaining similar eye levels and the distance increased when one of them sat down. In addition, when the *visitor* crouched next to the seated *owner*, both leaned on the desk closing the distance between them (Figure 10-t).

5.2 Computer-supported Social Interactions

Computer-supported social interactions are interactions that involve any sort of computing device (e.g. TV, tablet, laptop). The results showed that the 35% of computer-supported social interactions occurred in common spaces and 38% in personal spaces (Table 1). The results showed that socio-spatial formations are highly influenced by the *type of display* and in general, social proxemic distances are closer compared to unmediated interactions (Figure 12).

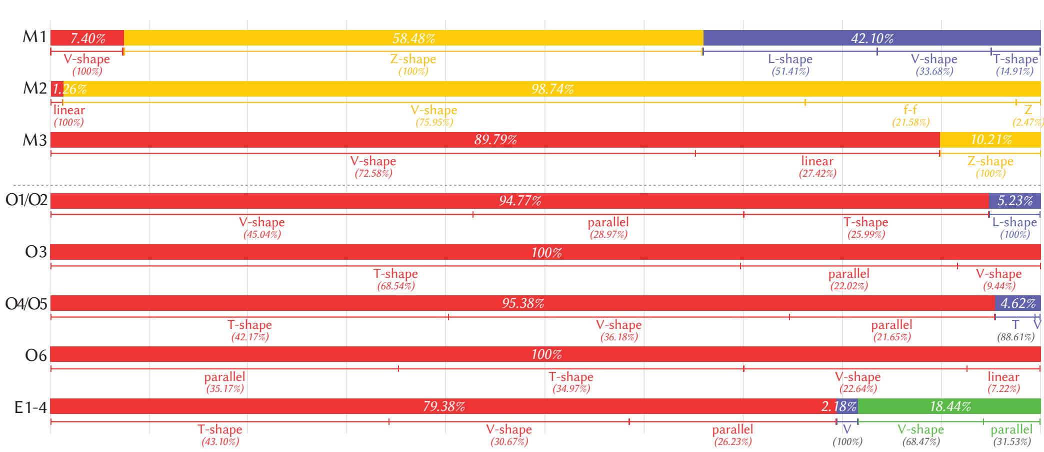

Fig. 11. The frequency of desk-relative arrangements for each spatial configuration during computer-supported social interactions are illustrated as bars. The frequency of formation shapes for each desk-relative arrangement are illustrated as lines underneath their corresponding bars. The frequency was calculated based on the total duration observed.

5.2.1 Common Desk Areas. At common desks, people usually brought their mobile computing devices with them, and often referred to information directly on these devices or projected onto a public display.

Personal mobile devices. When sharing information using personal devices in the middle of a discussion, people tended to maintain the formation they were in, and moved around the device instead. In *adjacent* or *perpendicular* arrangements, they moved close to each other, oriented their bodies towards the devices, and formed a *T-shape* (Figure 12 b) or *V-shape* (Figure 12 a). When people were in *across* arrangements, they turned their laptops towards the others (Figure 12 c) and used their displays as a public display.

Public display. When people used public displays, they actively rearranged themselves towards the display. The *V-shape* was predominant in all desk setups regardless of their previous formations as shown in Table 11 (Figure 12 d,e,f,g). When there are more than two people on the same side of the desk, the occupants seated closer to the display moved back slightly to prevent blocking the sight lines of others, as shown in Figure 12 i,j. Although this disconnected people from the desk, they kept this formation and used their thighs as a temporary table. The *reversed L-shape* formation was additionally observed when one person turned their chair to look at the public display while another person was looking at their own laptop display (Figure 12 f).

5.2.2 Personal Desk Areas. Similar to findings from Koutsolampros [28], we observed multiple computer-mediated social interactions near personal desk areas. Those usually involved discussing works-in-progress, which caused the owner's displays to be involved in the interaction. In most cases, people were working while sitting, which indicates that the display height was not ideal for the standing *visitor*. Although all the employees were using height-adjustable desks with articulating monitor arms, they rarely adjusted the setup. Instead, they rearranged their body positions and orientations towards the monitors similar to public vertical display scenarios [6] (Figure 12).

Desk owner's display. Displays oriented towards the desk owner encouraged visitors to arrange in an *adjacent* setup regardless of the desk configuration, and the *T-shape* was predominant in most cases (Figure 11). The visitors stayed relatively close to the *owner* and looked at the monitor as illustrated in Figure 12-n, o. Interviewees highlighted that the closer proxemic distance did not bother them as the display provided an external visual focal point. However, when there were partitions on the side of the desk, a larger T-shape was formed as the visitor preferred to lean against the partition. Pointing gestures were repeatedly seen with this formation shape.

The *parallel* shape was occasionally formed as well (Figure 11). Visitors often occupied the space behind the owner's chair and oriented their bodies towards the display, while the owner looked at and operated their computer (Figure 12-l). This was frequently seen but only lasting for short periods of time. The interviewees highlighted that this formation was helpful when making progress updates quickly and efficiently because avoiding eye contact indirectly prevents visitors from intervening.

On the other hand, for long-lasting computer supported social interactions, *V-shape* (Figure 12-r,s) and *L-shape* (Figure 12-p,q) were often used. Both the *visitor* and the *owner* of the desk moved back and oriented towards each other, while continuing to look at the display. The desk owners occupied the space slightly off-center, and *visitors* moved slightly closer to the display's centre point. The distance between them was closer than during unmediated social interactions, but the distance between the visitor and the desk was still relatively far. Therefore, when *visitors* wanted to look at the display more carefully, they bent over rather than moving closer illustrated in Figure 12-l-a. The interviews revealed that these long-lasting computer-mediated social interactions at personal desk areas were usually for *casual project updates* (e.g. scrum meetings) between collaborators.

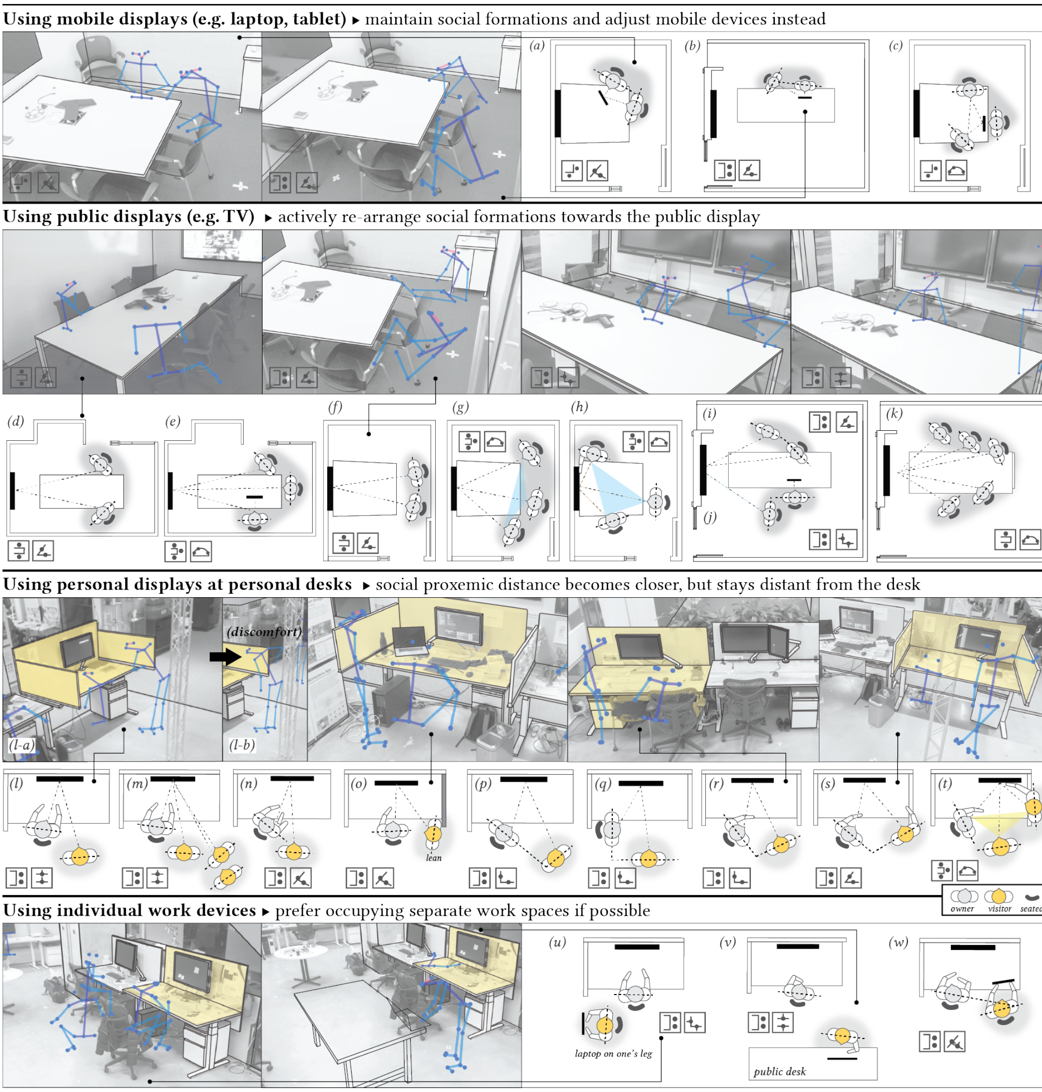

Fig. 12. Frequently observed socio-spatial formations during computer-supported interactions. Examples are categorized based on the type of display used.

Visitor's mobile devices. Visitors often brought and worked with their own mobile computing devices when they needed to work separately in the middle of collaboration. *Visitors* found separate workspaces (non-overlapped transactional spaces) near the personal desk area. For example, we observed one person bringing their chair and arranging in a *reversed L-shape*, and worked with their laptop on their leg (Figure 12-u). Another case showed a visitor moving to a nearby public table behind the desk owner and working individually in a *reversed Z-shape* (Figure 12-v). Interviews highlighted that they preferred to have a separate work area because working long-term in the other's personal space made them uncomfortable and made it difficult to concentrate.

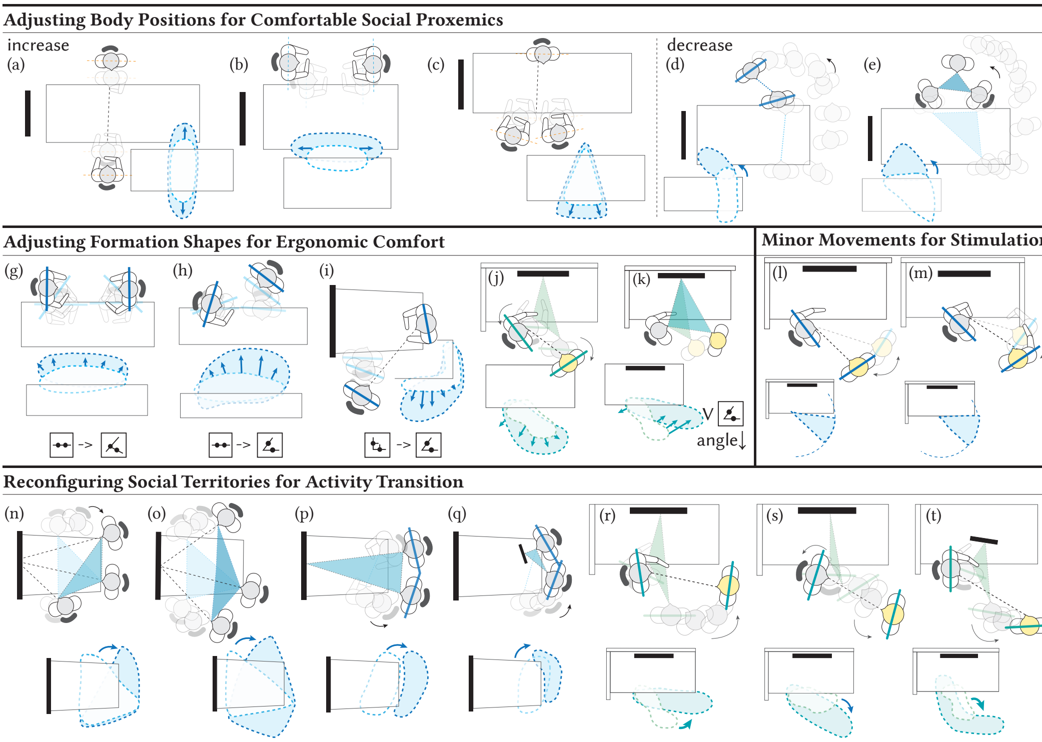

Fig. 13. Four types of socio-spatial formation transitions observed.

6 FINDINGS 2: FORMATION TRANSITIONS FOR SOCIAL COMFORT

Inspired by the work of Tong et al. [57], we also analyzed how socio-spatial formations change over time. We found four types of formation changes that occurred to remain socially comfortable within static environmental constraints: 1) body position adjustments for comfortable social proxemic distances, 2) formation shape adjustments for ergonomic comfort, and 3) minor movements for stimulation, and 4) social territory reconfiguration for concurrent multi-interactions.

6.1 Body Position Adjustments for Comfortable Social Proxemics

When face-to-face interactions last longer than about 2 minutes, occupants slowly adjust their positions to reach an ideal proxemic distance. For example, people subtly moved backwards over time and occupied a larger space as illustrated in Figure 13-a,b,c. In some cases, when occupants were arranged *across* the desk, they changed to an *adjacent* setup to close the distance between them (Figure 13-d,e). This was frequently observed in M2 and M3 where the depth of the table was greater than 1.2 m, and the vacant area behind the desk becomes occupied.

6.2 Formation Shape Adjustments for Ergonomic Comfort

Other socio-spatial transitions occurred to support comfortable and ergonomic conversations by changing formation shapes. This was frequently shown when unmediated social interactions lasted longer than two minutes. People changed their chair position and body orientation to face each other to minimize neck or back strain. For example, people who were arranged at common desk areas rolled away from the desk to form a *V-shape* or *face-to-face* shape and as shown in Figure 13-g,h,i. The social territory expands to the area farther behind the desk. Second, this was shown when the computer-supported social interactions lasted long. They often re-arranged themselves from *parallel* to *L-shape* or *V-shape* to create a shared transactional space to comfortably face each other while maintaining a reasonable viewing distance from the screen (Figure 13-j,k).

6.3 Minor Movements for Stimulation

At personal desk spaces, socio-spatial transitions were more frequent due to the standing status of *visitors*. *Visitors* moved around the *owner* while discussing by keeping similar distances (Figure 13-l,m). Interviews revealed that people did not notice that they moved during the conversation, but afterwards indicated that the flexibility of slight movement around the space brought a more comfortable experience to the discussion. In addition, when the conversations lasted longer, visitors unconsciously moved towards nearby interior elements, such as walls or furniture.

6.4 Social Territory Reconfiguration for Activity Transitions

Given the highly complicated nature of collaborative activities in the office, we observed that social territories changed when displays were included or excluded from the conversation. When occupants started to use public displays, they oriented towards the display, which leads to shape changes from *circular* to *semi-circular* (Figure 13-n,o,p). Some people even changed to an *adjacent* arrangement as shown in Figure 13-q. The social distance between the occupants reduced, and their social territory moved farther from the desk. Interviewees highlighted that when they are looking at the display together, they feel less uncomfortable being closer to others.

Similar changes were also observed at personal desks. When the display was removed from the conversation, the occupants changed into a *face-to-face* formation with a larger social distance. Therefore, the social territory expanded beyond the desk area, as shown in Figure 13-r,s,t. This is the opposite of public displays where people tended to move away from the desk when the display was included.

7 DISCUSSION

This work is a preliminary investigation to gain an overview of socio-spatial patterns in office layouts. Different from early work on proxemic theories [22] with *static* distances, our study reveals that socio-spatial formations are a *dynamic* concept which can be influenced by space size, desk size, interior elements (e.g. partitions, columns, walls, and doors), sitting or standing status, and visual focus. In this section, 1) we further discuss this dynamic concept of socio-spatial formations and how this can inform future office designs. Then, we discuss the opportunities for 2) future office planning tools and 3) interactive interiors that can enhance social comfort in the office. Finally, 4) we reflect on our research methods.

7.1 Dynamics of Socio-Spatial Formations to Inform Office Space Design

Similar to the work by Marshall [37], we revealed that *furniture* has a large influence on preferred socio-spatial formations. Building upon the works of Lawson [33], who argued that the seating arrangements around a desk are relevant to different types of collaborative interactions, we propose that the size and configuration of a desk are higher level factors that contribute to social arrangements. For example, Lawson showed that *adjacent* arrangements were predominant for collaboration scenarios, but we found that there is a threshold to the size of a desk at which people feel more socially comfortable occupying a different edge of the desk. For meeting spaces, designers first need to determine the desired social arrangements for a certain space, then choose an appropriate shaped desk to enhance social comfort. For instance, when the goal is to support *adjacent* arrangements at small-sized wall mounted table, designers can add additional edges to provide non-collinear edges for occupants.

Results also showed that *interior elements* could induce different socio-spatial formations. For instance, when the *surrounding wall* was too close to the desk, people reported that they felt uncomfortable sitting close to others. Also, nearby *desk partitions*, *walls*, or *columns* could provide comfortable areas by encouraging people to stand around them. Therefore, by looking at these elements with a social lens and using those as building blocks, interior designers can improve social comfort. Configuring interior elements can compensate for the constraints from architectural limitations as well.

Moreover, the intervention of *displays* in the conversation influenced socio-spatial formations. Different from Hall's work [22], our study showed that the acceptable proxemic distance becomes smaller during computer-mediated social interactions. Besides visual focus, the *ownership of the display* was found to be an influential factor. At personal desks, the *parallel* formation between the roles of *driver* and *observer* were witnessed similar to vertical public display setups [6], but without the *role changes*. Interviews highlighted that *visitors* tried to keep a farther distance from owners' devices to respect their personal space. Unlike meeting rooms that include a large table and TV, designers could also consider multiple small kiosk zones to arrange people in close formations by taking advantage of both *shared visual focus* and *public displays*, for work update discussions.

Lastly, unlike social interactions in *standing* situations [22, 27], the social proxemic distance becomes larger in interactions with a mixture of standing and sitting occupants. Several aspects caused this variation. The eye level difference between people standing and sitting causes ergonomic issues when they are located too close together. Also, the chair and seated body posture enlarges the occupant's personal space, which encourages others to stay farther away. Interior designers could use this knowledge when selecting and arranging furniture in offices. For limited spaces, designers can maximize social comfort by installing bar tables or intentionally placing guest chairs near personal desks.

7.2 Space Planning Tools to Support Social Comfort

There have been several systems to evaluate the physical characteristics of a space to support the design process. Most looked at the space from a topological perspective, and the social aspects considered in the system were mostly focused on *path simulation* [39, 40] or *visual privacy* [10]. However, our study revealed that social comfort in office spaces is not only a matter of visual privacy or walking distances. Based on our findings, we suggest several opportunities for future space analysis and simulation tools.

First, a future system could simulate which areas will be frequently occupied in a given design during social interactions from a micro-perspective. Our results revealed that this would be simulated differently based on the configuration of walls, desks, and partitions, and showed the potential for evaluating the level of spatial support in social interactions. Moreover, the simulation could be run for each type of social interaction (e.g. getting quick advice, long-term unmediated discussions, computer-supported progress updates), which reveals to different space-usage patterns. Inspired by works that include robots in the formation patterns [25, 38], the system could simulate computer-mediated social interactions by regarding displays as a type of human, and including them in the formation shape. The relationship between the display and the human can be defined in the system to distinguish the behavior of *visitor* and desk *owner*. Also, the system needs to be aware of the contextual information of the interior elements beyond just geometry, for example, whether the desk is for public use or personal use. The threshold distance is relatively larger for a personal desk setup, and this generates different socio-spatial patterns such as an *L-shape* in the *adjacent* arrangements, with an occupied space farther from the desk.

7.3 Interactive Interior Elements and Furniture for Social Comfort

Social interactions at personal desk areas are common in the office environment [48]. Informal desk visits were found to increase work productivity by letting people share work or progress quickly in a familiar area [3, 11]. However, our study revealed that the experience of social interactions at one's personal desk depends on a broad range of aspects. First, people visiting another person's desk exhibited different socio spatial formations, as they aimed to maintain a certain distance not to invade personal space. Another aspect was from the different sitting and standing statuses between the desk *owner* and the *visitor*, namely ergonomic discomfort due to the display or desk height configured to desk owner's preferences (Figure 12 l-b). We also found that the reason that people did not adjust the height of their desks or monitors was not because they did not want to adjust their work environment, but because they did not want to intervene and break the flow of a social interaction.

Robotic workstations or work environments have only focused on single-user interactions that automatically respond to the owner's anthropometric measurements [63] or habits [8]. The next generation of interactive furniture or workstations should support informal social interactions. The interaction technique needs to help people smoothly transition their perceptions of the display from a private display to a public one [6, 26].

7.4 F-formations to Evaluate Space Occupancy

We built upon Kendon's F-formation framework [27] to understand socio-spatial behaviours and office occupancy patterns. Our study showed that the F-formation framework can provide additional information for social contexts in prior occupant evaluation studies in HBI. Unlike the majority of existing works that collected individual occupant's presence data using localization methods and created heat-maps from an individual's position data [2, 59, 62], our approach provided deeper insight into how space is occupied with respect to groups of people in specific contexts. For example, we were able to find different socio-spatial formations for how the *visitor* and *owner* of a personal desk occupy space during different types of collaborative activities. Furthermore, the transitions between each socio-spatial formation provided an overview of the *dynamics in space usage* which can help space designers be aware of user's long-term social comfort.

7.5 Digital Ethnography with Anonymized Skeletons

Our digital ethnography study is based on video frames of occupant's skeletons generated using computer vision techniques. We captured and distilled the body movements of occupant's skeletonized representations in a manner detailed enough to infer and observe socio-spatial formations. Anonymized skeletons allowed privacy-preserving analysis, which encouraged all the occupants to participate in our study with fewer concerns. Also, our method speeds up the social interaction classification process by automatically counting the number of occupants (skeletons) in the scene, and makes it easy to deal with large-scale data.

However, there were several technical limitations. First, our use of computer vision omitted the detection of non-fixed items, such as chairs or laptops, which play an important role in socio-spatial patterns in the office environment. As a result, we needed to occasionally consult the masked raw video. With further advancements in computer vision, the relevant items could be detected, located, and tracked reliably, maintaining anonymity. Moreover, real-life situations cause occlusion scenarios which degrade the quality of human body detection. This problem was mitigated by installing multiple cameras for a single area in our study. Conversely, some coats, hangers and truss structures generated false positives in the human detection, but those were easily excluded since they are seen as static skeletons.

Despite these limitations, we believe this advanced method can support future ethnographic studies in three domains. First, our method can be applied to public ethnographic studies, which have historically been done by co-located human observers for privacy concerns [6]. Second, our method can be used to understand socio-spatial characteristics in sensitive contexts, such as hospitals. For example, this can contribute to the study of Thomsen et al. [56], which studied social formations in sensitive medical consultations. Third, compared to using other pervasive sensors that support indoor localization [2, 62], our method could collect embodied behaviours, such as body languages, spatial formations, and poses, without the need for devices that are both cumbersome for the individual and costly for large-scale studies.

8 STUDY LIMITATIONS & FUTURE WORK

There are several limitations that call for further investigation in the future. First, a large amount of variability in real work environments made it challenging to pinpoint the exact influences on observed socio-spatial formations. In this study, we focused on the frequency of each formation pattern along with interview results with a large data set. Conducting a controlled study could be a likely next step for a more precise investigation. Also, collecting the level of social comfort for each formation in the future could provide richer knowledge in terms of social comfort in space.Second, sound and lights, which are potential influences on social interactions, were ignored in this study. There were some instances where occupants wore headphones before the visitor approached, and others were people were having conversations in a darker environment. This could be investigated in the future. Third, our findings from common spaces and personal work spaces are not feasible to inform offices with hot-desking. Further investigation is needed to explore the influence of common desks with personal laptops for individual work settings. Fourth, due to the ethical research setup, we could not accurately collect the content (e.g. project-related discussion, non-work chat) or type (e.g. scrum meeting, asking for advice) of social interactions. Interviews provided a glimpse into these aspects by recalling or guessing who the skeletons are just by identifying unique body language or poses. In the future, we can ask occupants to manually log the contexts, as a diary study. Context-recognition from body language or poses using advanced machine-learning techniques could also automatically add an additional layer of information. Moreover, we did not consider cultural aspects while analyzing socio-spatial formations despite its importance [13, 22]. Although we believe the amount of data collected in diverse locations from multicultural employees compensated for this limitation, we could further investigate demographic information from the skeletons [1]. Finally, we briefly observed that the path people took while approaching other's desks was not always the most efficient path; instead, they took the path that allowed the desk *owners* to see them approaching in their peripheral vision. However, we could not accurately the extract the path they took just by observing them through videos from perspective views. In the future, reconstructing 2D skeletons into 3D models in the architectural space could be a potential next step to obtain accurate movements from the occupants.

9 CONCLUSION

This an exploratory study to investigate the influence of spatial characteristics on socio-spatial formations. We captured a rich array of social arrangements exhibited in a office environment for two weeks with corresponding occupants' space perceptions. We analyzed collected data using Skeletonographer, that we implemented to generate skeletonized representations, and to play back and annotate skeleton data. Our findings revealed that desk sizes, desk configuration, walls, partitions, and sitting and standing status contribute to different preferred socio-spatial formations during unmediated discussions, while the type and ownership of displays have more significant influence during computer-mediated social interactions. We also found that socio-spatial formations change over time to maintain ergonomic and social comfort in long-term interactions. Based on these findings, we propose that future office space designers could plan desired socio-spatial formations at a given space while arranging interior elements to maximize social comfort. We also suggest that this knowledge can inform opportunities for space planning and analysis tools as well as interactive furniture in the future.

REFERENCES

[1] D. Adjeroh, D. Cao, M. Piccirilli, and A. Ross. 2010. Predictability and correlation in human metrology. In *2010 IEEE International Workshop on Information Forensics and Security*. 1–6. https://doi.org/10.1109/WIFS.2010.5711470

[2] Hamed S. Alavi, Himanshu Verma, Jakub Mlynar, and Denis Lalanne. 2018. The Hide and Seek of Workspace: Towards Human-Centric Sustainable Architecture. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 75, 12 pages. https://doi.org/10.1145/3173574.3173649

[3] Thomas J. Allen and Peter G. Gerstberger. 1973. A Field Experiment to Improve Communications in a Product Engineering Department: The Nonterritorial Office. *Human Factors* 15, 5 (1973), 487–498. https://doi.org/10.1177/001872087301500505 arXiv:https://doi.org/10.1177/001872087301500505

[4] Irwin Altman. 1975. The Environment and Social Behavior: Privacy, Personal Space, Territory, and Crowding. (1975).

[5] Louis Atallah and Guang-Zhong Yang. 2009. The use of pervasive sensing for behaviour profiling âĂŤ a survey. *Pervasive and Mobile Computing* 5, 5 (2009), 447 – 464. https://doi.org/10.1016/j.pmcj.2009.06.009

[6] Alec Azad, Jaime Ruiz, Daniel Vogel, Mark Hancock, and Edward Lank. 2012. Territoriality and Behaviour on and Around Large Vertical Publicly-shared Displays. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, New York, NY, USA, 468–477. https://doi.org/10.1145/2317956.2318025

[7] Alan Backhouse and Peter Drew. 1992. The design implications of social interaction in a workplace setting. *Environment and Planning B: Planning and Design* 19, 5 (1992), 573–584.

[8] Gilles Bailly, Sidharth Sahdev, Sylvain Malacria, and Thomas Pietrzak. 2016. LivingDesktop: Augmenting Desktop Workstation with Actuated Devices. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 5298–5310. https://doi.org/10.1145/2858036.2858208

[9] Till Ballendat, Nicolai Marquardt, and Saul Greenberg. 2010. Proxemic Interaction: Designing for a Proximity and Orientation-Aware Environment. *ACM International Conference on Interactive Tabletops and Surfaces, ITS 2010*, 121–130. https://doi.org/10.1145/1936652.1936676

[10] Mateus Paulo Beck. 2012. Visibility and Exposure in Workspaces. In *Proceedings of the 9th International Space Syntax Symposium*.

[11] Aoife Brennan, Jasdeep S. Chugh, and Theresa Kline. 2002. Traditional versus Open Office Design: A Longitudinal Field Study. *Environment and Behavior* 34, 3 (2002), 279–299. https://doi.org/10.1177/0013916502034003001 arXiv:https://doi.org/10.1177/0013916502034003001

[12] Malcolm J. Brookes and Archie Kaplan. 1972. The Office Environment: Space Planning and Affective Behavior. *Human Factors* 14, 5 (1972), 373–391. https://doi.org/10.1177/001872087201400502 arXiv:https://doi.org/10.1177/001872087201400502

[13] Chloë Brown, Christos Efstratiou, Ilias Leontiadis, Daniele Quercia, and Cecilia Mascolo. 2014. Tracking serendipitous interactions: how individual cultures shape the office. In *CSCW*.

[14] Zhe Cao, Tomas Simon, Shih-En Wei, and Yaser Sheikh. 2017. Realtime multi-person 2d pose estimation using part affinity fields. In *2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*. IEEE, 1302–1310.

[15] Maria Danninger, Roel Vertegaal, Daniel P. Siewiorek, and Aadil Mamuji. 2005. Using Social Geometry to Manage Interruptions and Co-worker Attention in Office Environments. In *Proceedings of Graphics Interface 2005 (GI '05)*. Canadian Human-Computer Communications Society, School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 211–218. http://dl.acm.org/citation.cfm?id=1089508.1089543

[16] Francis Duffy and Kenneth Powell. 1997. The new office. (1997).

[17] Anne-Laure Fayard and John Weeks. 2007. Photocopiers and Water-coolers: The Affordances of Informal Interaction. *Organization Studies* 28, 5 (2007), 605–634. https://doi.org/10.1177/0170840606068310 arXiv:https://doi.org/10.1177/0170840606068310

[18] Thomas F. Gieryn. 2002. What Buildings Do. *Theory and Society* 31, 1 (2002), 35–74.

[19] Saul Greenberg, Nicolai Marquardt, Till Ballendat, Rob Diaz-Marino, and Miaosen Wang. 2011. Proxemic Interactions: The New Ubicomp? *Interactions* 18, 1 (Jan. 2011), 42–50. https://doi.org/10.1145/1897239.1897250

[20] Jens Emil Grønbæk, Henrik Korsgaard, Marianne Graves Petersen, Morten Henriksen Birk, and Peter Gall Krogh. 2017. Proxemic Transitions: Designing Shape-Changing Furniture for Informal Meetings. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 7029–7041. https://doi.org/10.1145/3025453.3025487

[21] G. Guest, K.M. MacQueen, and E.E. Namey. [n. d.]. *Applied Thematic Analysis.*
[22] E.T. Hall and Copyright Paperback Collection (Library of Congress). [n. d.]. *The Hidden Dimension.*
[23] Barry P. Haynes. 2008. The impact of office layout on productivity. *Journal of Facilities Management* 6, 3 (2008), 189–201. https://doi.org/10.1108/14725960810885961 arXiv:https://doi.org/10.1108/14725960810885961
[24] Bill Hillier and Julienne Hanson. 1984. *The Social Logic of Space.* Cambridge University Press. https://doi.org/10.1017/CBO9780511597237
[25] H. Huettenrauch, K. S. Eklundh, A. Green, and E. A. Topp. 2006. Investigating Spatial Relationships in Human-Robot Interaction. In *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems.* 5052–5059. https://doi.org/10.1109/IROS.2006.282535
[26] Junko Ichino, Kazuo Isoda, Tetsuya Ueda, and Reimi Satoh. 2016. Effects of the Display Angle on Social Behaviors of the People Around the Display: A Field Study at a Museum. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16).* ACM, New York, NY, USA, 26–37. https://doi.org/10.1145/2818048.2819938
[27] Adam Kendon. 1990. *Conducting Interaction: Patterns of Behavior in Focused Encounters.* Cambridge University Press.
[28] Petros Koutsolampros, K Sailer, R Haslem, M Austwick, and Tasos Varoudis. 2017. Big Data and Workplace Micro-Behaviours: A closer inspection of the social behaviour of eating and interacting.
[29] Peter Gall Krogh, Marianne Graves Petersen, Kenton O'Hara, and Jens Emil Groenbaek. 2017. Sensitizing Concepts for Socio-spatial Literacy in HCI. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17).* ACM, New York, NY, USA, 6449–6460. https://doi.org/10.1145/3025453.3025756
[30] H. Kuzuoka, Y. Suzuki, J. Yamashita, and K. Yamazaki. 2010. Reconfiguring spatial formation arrangement by robot body orientation. In *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI).* 285–292. https://doi.org/10.1109/HRI.2010.5453182
[31] Davis L. Masten and Tim M.P. Plowman. 2010. Digital Ethnography: The Next Wave in Understanding the Consumer Experience. *Design Management Journal (Former Series)* 14 (06 2010), 75 – 81. https://doi.org/10.1111/j.1948-7169.2003.tb00044.x
[32] B. Lawson. [n. d.]. *How Designers Think: The Design Process Demystified.*
[33] B. Lawson. [n. d.]. *The Language of Space.*
[34] Bokyung Lee, Sindy Wu, Maria Jose Reyes, and Daniel Saakes. 2019. The Effects of Interruption Timings on Autonomous Height-Adjustable Desks That Respond to Task Changes. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19).* ACM, New York, NY, USA, Article 328, 10 pages. https://doi.org/10.1145/3290605.3300558
[35] Paul Luff and Christian Heath. 1998. Mobility in Collaboration. In *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work (CSCW '98).* ACM, New York, NY, USA, 305–314. https://doi.org/10.1145/289444.289505
[36] Nicolai Marquardt, Ken Hinckley, and Saul Greenberg. 2012. Cross-device Interaction via Micro-mobility and F-formations. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology (UIST '12).* ACM, New York, NY, USA, 13–22. https://doi.org/10.1145/2380116.2380121
[37] Paul Marshall, Yvonne Rogers, and Nadia Pantidi. 2011. Using F-formations to Analyse Spatial Patterns of Interaction in Physical Environments. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work (CSCW '11).* ACM, New York, NY, USA, 445–454. https://doi.org/10.1145/1958824.1958893
[38] Takahiro Matsumoto, Mitsuhiro Goto, Ryo Ishii, Tomoki Watanabe, Tomohiro Yamada, and Michita Imai. 2018. Where Should Robots Talk?: Spatial Arrangement Study from a Participant Workload Perspective. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI '18).* ACM, New York, NY, USA, 270–278. https://doi.org/10.1145/3171221.3171265
[39] Danil Nagy, Damon Lau, John Locke, James Stoddart, Lorenzo Villaggi, Ray Wang, Dale Zhao, and David Benjamin. 2017. Project Discover: An Application of Generative Design for Architectural Space Planning. https://doi.org/10.22360/simaud.2017.simaud.007
[40] Danil Nagy, Lorenzo Villaggi, James Stoddart, and David Benjamin. 2017. The Buzz Metric: A Graph-based Method for Quantifying Productive Congestion in Generative Space Planning for Architecture. *Technology|Architecture + Design* 1, 2 (2017), 186–195. https://doi.org/10.1080/24751448.2017.1354617 arXiv:https://doi.org/10.1080/24751448.2017.1354617
[41] Office of the privacy commissioner of canada. 2019. Canada on Covert Video Surveillance in the Private Sector. (jan 2019). Retrieved 2019-01-05 from https://www.priv.gc.ca/en/privacy-topics/surveillance-and-monitoring/gd_cvs_20090527/
[42] Takeshi Oozu, Aki Yamada, Yuki Enzaki, and Hiroo Iwata. 2017. Escaping Chair: Furniture-Shaped Device Art. 403–407. https://doi.org/10.1145/3024969.3025064
[43] Jeni Paay, Jesper Kjeldskov, and Mikael B. Skov. 2015. Connecting in the Kitchen: An Empirical Study of Physical Interactions While Cooking Together at Home. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW '15).* ACM, New York, NY, USA, 276–287. https://doi.org/10.1145/2675133.2675194

[44] Mahbub Rashid, Kevin Kampschroer, Jean Wineman, and Craig Zimring. 2006. Spatial Layout and Face-to-Face Interaction in Offices—A Study of the Mechanisms of Spatial Effects on Face-to-Face Interaction. *Environment and Planning B: Planning and Design* 33, 6 (2006), 825–844. https://doi.org/10.1068/b31123

[45] Kerstin Sailer, Andrew Budgen, and Nathan Lonsdale. 2008. Evidence-Based Design : Theoretical and Practical Reflections of an Emerging Approach in Office Architecture.

[46] Kerstin Sailer, Petros Koutsolampros, Martin Zaltz Austwick, Tasos Varoudis, and Andy Hudson-Smith. 2016. Measuring interaction in workplaces. In *Architecture and Interaction.* Springer, 137–161.

[47] Kerstin Sailer and Alan Penn. 2009. Spatiality and transpatiality in workplace environments. Royal Institute of Technology (KTH).

[48] K Sailer, R Pomeroy, and R Haslem. 2015. Data-driven design—Using data on human behaviour and spatial configuration to inform better workplace design. *Corporate Real Estate Journal* 4 (02 2015).

[49] L. Scott-Webber. [n. d.]. *In Sync: Environmental Behavior Research and the Design of Learning Spaces.*

[50] Ben Rydal Shapiro and Rogers Hall. 2018. Personal Curation in a Museum. *Proc. ACM Hum.-Comput. Interact.* 2, CSCW, Article 158 (Nov. 2018), 22 pages. https://doi.org/10.1145/3274427

[51] Robert Sommer. [n. d.]. *Personal space; the behavioral basis of design.*

[52] Robert Sommer. 1967. Small group ecology. *Psychological bulletin* 67, 2 (1967), 145.

[53] Yuichiro Takeuchi. 2010. Weightless Walls and the Future Office. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10).* ACM, New York, NY, USA, 619–628. https://doi.org/10.1145/1753326.1753419

[54] Yuichiro Takeuchi and Jean You. 2014. Whirlstools: kinetic furniture with adaptive affordance. In *CHI Extended Abstracts.*

[55] Maurice Ten Koppel, Gilles Bailly, Jörg Müller, and Robert Walter. 2012. Chained Displays: Configurations of Public Displays Can Be Used to Influence Actor-, Audience-, and Passer-by Behavior. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12).* ACM, New York, NY, USA, 317–326. https://doi.org/10.1145/2207676.2207720

[56] Josephine Raun Thomsen, Peter Gall Krogh, Jacob Albæk Schnedler, and Hanne Linnet. 2018. Interactive Interior and Proxemics Thresholds: Empowering Participants in Sensitive Conversations. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18).* ACM, New York, NY, USA, Article 68, 12 pages. https://doi.org/10.1145/3173574.3173642

[57] Lili Tong, Audrey Serna, Simon Pageaud, Sébastien George, and Aurélien Tabard. 2016. It's Not How You Stand, It's How You Move: F-formations and Collaboration Dynamics in a Mobile Learning Game. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16).* ACM, New York, NY, USA, 318–329. https://doi.org/10.1145/2935334.2935343

[58] Alasdair Turner, Maria Doxa, David O'Sullivan, and Alan Penn. 2001. From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environment and Planning B: Planning and Design* 28, 1 (2001), 103–121. https://doi.org/10.1068/b2684 arXiv:https://doi.org/10.1068/b2684

[59] Himanshu Verma, Hamed S. Alavi, and Denis Lalanne. 2017. Studying Space Use: Bringing HCI Tools to Architectural Projects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17).* ACM, New York, NY, USA, 3856–3866. https://doi.org/10.1145/3025453.3026055

[60] Luke Vink, Viirj Kan, Ken Nakagaki, Daniel Leithinger, Sean Follmer, Philipp Schoessler, Amit Zoran, and Hiroshi Ishii. 2015. TRANSFORM As Adaptive and Dynamic Furniture. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15).* ACM, New York, NY, USA, 183–183. https://doi.org/10.1145/2702613.2732494

[61] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology (UIST '04).* ACM, New York, NY, USA, 137–146. https://doi.org/10.1145/1029632.1029656

[62] Mani Williams, Jane Burry, Asha Rao, and Nathan Williams. 2015. A System for Tracking and Visualizing Social Interactions in a Collaborative Work Environment. In *Proceedings of the Symposium on Simulation for Architecture & Urban Design (SimAUD '15).* Society for Computer Simulation International, San Diego, CA, USA, 1–4. http://dl.acm.org/citation.cfm?id=2873021.2873022

[63] Yu-Chian Wu, Te-Yen Wu, Paul Taele, Bryan Wang, Jun-You Liu, Pin-sung Ku, Po-En Lai, and Mike Y. Chen. 2018. ActiveErgo: Automatic and Personalized Ergonomics Using Self-actuating Furniture. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18).* ACM, New York, NY, USA, Article 558, 8 pages. https://doi.org/10.1145/3173574.3174132

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